

https://dspace.org/

Examining the development of topic specific PCK in stoichiometry of three practicing teachers through a lesson study

Mudzatsi, Tarisai

2017

https://hdl.handle.net/10539/26452

Mudzatsi, Tarisai (2017) Examining the development of topic specific PCK in stoichiometry of three practicing teachers through a lesson study, University of the Witwatersrand, Johannesburg, https://hdl.handle.net/10539/26452

Downloaded from a DSpace repository. https://dspace.org/

Examining the development of Topic Specific PCK in Stoichiometry of three practicing teachers through a lesson study



A research report
submitted to the Faculty of Science, School of Education,
University of the Witwatersrand, Johannesburg, South Africa, in partial fulfilment of the award of Master of Science (MSc.) in Science Education

Tarisai Mudzatsi

Protocol Number: 2015ECE039M
Student Number: 859057

Supervisor: Dr. Elizabeth Mavhunga

March, 2017

Copyright Notice

The copyright of this research report vests in the University of the Witwatersrand, Johannesburg, South Africa, in accordance with the University's Intellectual Property Policy. No portion of the text may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, including analogue and digital media, without prior written permission from the University. Extracts of, or quotations from this thesis may, however, be made in terms of Section 12 or 13 of the South African Copyright Act No. 98 of 1978 (as amended),for non-commercial or educational purposes. Full acknowledgement must be made to the author and the University. An electronic version of this thesis is available on the Library webpage **(www.wits.ac.za/library)** under "Research Resources". For permission requests, please contact the University Legal Office or the University Research office **(www.wits.ac.za).**

Declaration

I declare 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 honor as a post-graduate student at Wits University and recognize that by maintaining the declaration, I maintain both my own integrity and that of the University of which I am a member.

Tarisai Mudzatsi

_____

Signature of candidate

Date: 17/03/2017

Dedication

I dedicate this work to my mother Mrs. Gladys Mudzatsi and my late father Mr Lucas Dzikamai Mudzatsi who together thrived to make me what I am.

Acknowledgements

Firstly I would like to thank the almighty God, creator of heaven and earth for the opportunity to conduct this work. To my supervisor, Dr. Elizabeth Mavhunga, I extend the most sincere gratitude for the continuous support, insightful guidance and motivation that she professionally executed. Her guidance, expertise, encouragement and above all, humility are deeply appreciated: whose strength of character is beyond reproach.

To the rest of the lesson study group members, whose experience and contributions have certainly helped build a better teacher out of me. Professor Rollnick, Dr. Nakedi and Stephen Andrew Malcolm for pointing us to relevant literature, you have a vision for an informed and authoritative citizenry. All your comments are overwhelmingly valuable.

The financial assistance of the National Research Foundation (NRF) towards this research is hereby acknowledged. Opinions expressed and conclusions arrived at, are those of the author and are not necessarily to be attributed to the NRF.

I also extend my sincere gratitude to Dr. Jabulani Sibanda who edited the manuscript in a very short space of time; he has taught me that it is never too late, many thanks. I appreciate the work of Lerato Makabane, who recorded the videos; they were all superb; that was true choreography. All your sacrifices are worthwhile and my guarantees to you all: the limit is beyond the sky.

To my daughter, Kimberly Nenyasha and spouse Philisiwe, a reason to go on, many thanks for the continuous support, encouragement and patience, may grace remain in your hearts forever.

Last, but certainly not least, the learners and teachers who took their time on Saturdays to attend classes, write pre- and post-tests and showing a willingness to learn stoichiometry, I thank you all so much and certainly, your efforts will be rewarded because knowledge conquers fear.
Sincere gratitude to all who were directly or indirectly involved in this study, school administrators and support staff, teachers, Heads of Departments and school Principals, your contributions have gone a long way in assisting me to put this work together.
God bless you all, ngiyabonga kakhulu, inkosi inibusise nonke, ndinotenda mwari akukomborerei mese, ndo livhuwa nga maanda mudzimu vhani shudufhadze nothe; Inkomu Xikwembu ximikatekisa hinkwenhu.

Abstract

Professional learning communities are generally regarded as having a positive impact in improving and developing teacher knowledge. Literature has shown that group planning and professional learning communities have an impact on the quality of teaching and subsequent improvement in learner performance. Practicing teachers, preservice teachers, education authorities, curriculum advisors and teacher educators all thrive to find out about the kind of teaching that brings about effective learning inside classrooms, the most appropriate approach to improve teaching and learning in class, and in particular, science classes, remains vague, though. This study examines how teacher knowledge is developed in the context of a lesson study within a specific concept of the topic stoichiometry: the 'mole'. The case of three practicing science teachers is considered through the observation of their interactions with teacher educators during the five (5) weeks in which the participant teachers planned, taught and reflected on the mole concept together with science teacher educators and science teacher education specialists. A pre-test is administered to the participant teachers at the beginning of the study; this is followed by intervention discussions based on the concept of the mole. Each of the participants then teaches the lesson to 11th grade learners in their school, each lesson is reflected upon and an iterative cycle of teaching and re-teaching the concept describes the lesson study approach used in this study. At the end of the intervention, a post-test is administered to the three participant teachers. The analysis and description of the teachers' responses to structured test items before and after the topic specific intervention and verbal contributions during meetings are sources of qualitative data in this study. The qualitative data about topic specific pedagogy and the interaction of TSPCK components obtained in this study is used as evidence to show that topic-specific interventions assist teachers in developing pedagogical content knowledge in science education.

Keywords: Lesson study; pedagogical content knowledge; topic-specific pedagogical content knowledge; stoichiometry; the mole.

Table of contents

Copyright notice..... i
Declaration..... ii
Dedication..... iii
Acknowledgements..... iv
Abstract..... v
Table of Contents..... vi
List of Appendices..... ix
List of Figures..... x
List of Tables..... xi
List of Acronyms..... xii

CHAPTER ONE - GENERAL INTRODUCTION TO THE STUDY
1.1 Introduction..... 1
1.2 Purpose of the study..... 2
1.3 Rationale..... 3
1.4 Research questions..... 5
1.5 Value of findings to science education research..... 5

CHAPTER TWO - LITERATURE REVIEW
2.1 Introduction..... 7
2.2 PCK as a valued construct in science education..... 7
2.3 TSPCK as a construct in science education..... 7
2.4 Lesson study as a vehicle for PCK development..... 8
2.5 CoRe as a platform for capturing developing TSPCK in a lesson study..... 9
2.6 Learning difficulties in stoichiometry and the mole concept..... 9
2.7 Identifying gaps in literature..... 10
2.8 Conclusion..... 10

CHAPTER THREE - RESEARCH METHODOLOGY
3.1 Introduction..... 11
3.2 Overview of the methodology used in the study..... 11
3.3 Research design..... 11
3.4 Research strategy-case study..... 13
3.5 Participants..... 14
3.6 Treatment – Intervention to developing TSPCK..... 14
3.7 Data collection..... 16
3.8 Analysis of data..... 17
3.9 Context..... 18

3.10 Sources of data, validity, reliability and ethical considerations..... 18
3.11 Conclusion..... 21

CHAPTER FOUR – THE DEVELOPMENT OF A RUBRIC FOR EVALUATING ENACTED PCK
4.1 Introduction..... 22
4.2 Rationale for a rubric to grade the quality of enacted TSPCK..... 22
4.3 Developing a rubric for grading TSPCK episodes in the practice of teaching science 23
4.4 Analysis of identified TSPCK episodes..... 25
4.4.1 TSPCK episodes in Teacher Liso's teaching..... 26
4.4.2 TSPCK episodes in Teacher Qondi's teaching..... 32
4.5 The emerging TSPCK rubric with examples from a pilot study..... 37
4.6 Concluding remarks..... 37

CHAPTER FIVE - FINDINGS
5.1 Introduction..... 39
5.2 A brief account of data collection..... 39
5.3 A brief account of data analysis..... 40
5.4 Findings..... 43
5.5 Impact of the lesson study..... 44
5.5.1 Positive shifts in the quality of espoused TSPCK in stoichiometry..... 44
5.5.2 Positive shifts in the quality of enacted TSPCK in stoichiometry..... 52
5.6 Summary of major findings..... 63

CHAPTER SIX – CONCLUSIONS AND RECOMENDATIONS
6.1 Overview of the study..... 67
6.2 Brief summary of the study..... 67
6.2.1 How does a lesson study on stoichiometry influence the development of TSPCK in the topic of three practicing teachers?..... 68
6.2.2 How does the TSPCK developed in stoichiometry translate into practicing teachers' classroom practices?..... 69
6.3 Contributions of the study to new knowledge..... 69
6.4 Reflections on the methodology used..... 70
6.5 Implications for teacher development..... 70
6.6 Review of validity, reliability and ethical issues..... 71
6.7 Limitations of the study..... 72
6.8 Recommendations..... 72
6.8.1 Creating baseline knowledge for science teachers in stoichiometry..... 72

6.8.2 Informing curriculum developers on the need to spend more time on teaching stoichiometry..... 73
6.8.3 Professional learning communities at school, cluster, district and regional levels 73
6.8.4 Depiction of the mole concept in textbooks..... 73

REFERENCES..... 75

List of Appendices

APPENDIX I	Stoichiometry TSPCK Achievement tool.....	82
APPENDIX II	Rubric for espoused TSPCK.....	95
APPENDIX III	Consent tool for participating project members and practicing teachers.....	96
APPENDIX IV	Consent form for Principals of the schools involved in the study.....	100
APPENDIX V	Consent form for learners.....	103
APPENDIX VI	Consent form for parents.....	105
APPENDIX VII	GDE approval letter.....	108
APPENDIX VIII	Human Sciences Research committee approval letter.....	109
APPENDIX IX	Lesson plan on the mole concept.....	110

List of Figures

2.1	TSPCK model (Mavhunga and Rollnick, 2013).....	8
5.1	An extract of a TSPCK rubric in a planning context (espoused TSPCK rubric)..	40
5.2	Espoused TSPCK rubric showing component interactions.....	42
5.3	An extract from Teacher Alex's pre- and post-test responses to item on the Component what is difficult to each.....	45
5.4	An extract from Teacher Andy's example of a 1-category jump in the component of what is difficult to teach.....	47
5.5	An extract from Gigi showing another 2-category improvement in TSPCK.....	49
5.6	An extract from Teacher Gigi showing a 1-category shift in TSPCK.....	50
5.7	An extract from Teacher Alex that shows no improvement in the TSPCK score.	51

List of Tables

1.1	2011-2014 senior certificate physical science results	3
3.1	Teaching qualifications and experiences of participants	14
3.2	Structure of discussion sessions in the lesson study	15
3.3	Schedule of treatment and classroom observation	16
3.4	Summary of how data were collected	16
4.1	Bibliographical information of participant teachers in pilot study	24
4.2	Overview of evident TSPCK in pilot study lessons	25
4.3	The nature and types of TSPCK observed in pilot videos	26
4.4	An example of a 2-component TSPCK episode	27
4.5	An example of a 3-component TSPCK episode	29
4.6	An example of a 4-component TSPCK episode	30
4.7	Another example of a 2-component TSPCK episode	32
4.8	Another example of a 3-component TSPCK episode	33
4.9	An example of a 4-component TSPCK episode	34
4.10	Developed rubric for the analysis of enacted TSPCK components	37
5.1	Pre- and post-TSPCK scores of the 3 practicing teachers	41
5.2	Frequency of mole related contributions in teacher talk during meetings	52
5.3	Contributions related to TSPCK	53
5.4	Rubric for the analysis of enacted TSPCK	57
5.5	Overview of evident TSPCK episodes in the teaching of participant teachers	58
5.6	An example of a 2-component ‘Basic’ TSPCK episode	59
5.7	An example of a 3-component ‘Moderate’ TSPCK episode	60
5.8	An example of a 4-component TSPCK episode	61

List of Acronyms

CS	Curricular Saliency
CTS	Conceptual Teaching Strategies
LPK	Learner Prior Knowledge
PCK	Pedagogical Content Knowledge
PE	Potential energy
RP	Representations and Analogies
TSPCK	Topic Specific Pedagogical Content Knowledge
WD	What is Difficult to teach?

CHAPTER ONE

1. General introduction to the study

This chapter begins by giving a brief description of a lesson study intervention as a form of a teacher development initiative that develops teacher knowledge and pedagogical practice. The need to develop Topic Specific Pedagogical Content knowledge (TSPCK) in specific disciplines and topics is outlined. The study is placed in a South African context and in the specific topic of stoichiometry and the mole concept. Teachers who lack both content and pedagogical knowledge for teaching science characterize the current state of science education in South Africa. Poor performance of learners in diagnostic, benchmarking tests and national Matriculation examinations all provide a rationale for studies that look into the pedagogical practices of science teachers. Questions on the mole are reportedly poorly answered in these tests. The rationale for this study is discussed in this context in this chapter together with the aims of the research, and the research questions that give the study direction. I conclude this chapter by highlighting the value of the findings of this study to science education research.

1.1 Introduction

This explanatory qualitative study examines the development of teacher knowledge in the context of a lesson study. The learning of science by students depends on many factors which include the teachers' knowledge of science and how to make science comprehensible to students. There is a need for the development of teacher conceptual instructional strategies that enhance learner understanding of scientific concepts. However, the teaching of physical sciences (Physics with Chemistry) in South African schools remains problematic as evidenced by consistently poor learner performance in both mathematics and physical sciences as reported by Makgato and Mji, (2006) who listed the factors that contribute to poor learner performance in both mathematics and science, these factors range from poor conceptual teaching strategies, content knowledge, motivation, laboratory use, non-completion of syllabus and other factors related to the role of parents or language use. Other authors have reported a number of shortcomings in the teaching and learning of mathematics and science in South Africa (Jansen, 2004 in press; Reddy, 2004; Howie, 2003; Beaton, 1995). The fundamental goal of science education is quality science teaching in the classroom. From the factors identified by Makgato and Mji (2006), this study draws on teacher transformation of science knowledge for learner understanding which fuses teacher subject content knowledge with pedagogical practice that enhances learner understanding. Concerns have been raised about the understanding of baseline knowledge in chemistry, which is part of the physical science curriculum, in particular, reaction stoichiometry and the concept of the mole (Packer, 1988; Schmidt, 1987; Cerveliati et. al, 1982). Evaluations of teacher education have also shown that there are missing connections between

subject-matter knowledge, pedagogical competence with real life practice in classrooms (e.g. Bransford, 2004; Cochran, King, & Dereuter, 1991; Goodlad, 1990; Hewson & Hewson, 1988; NOKUT, 2006; Norgesnettrådet, 2002). Moreover, relating theory to practice is of concern to teacher education and the design of continuous teacher development programs. Chan and Yung (2015) have realized that little is known about how experienced teachers develop their PCK via reflection-in-action during their moment-to-moment classroom instruction. Dahsah and Coll (1987) noted the use of algorithms with little understanding of the underlying concepts in responding to science questions. Educational reforms have also not fostered understanding of some science concepts. Curriculum developers are recommended to specify a need for conceptual understanding in the teaching of science. The construct of pedagogical content knowledge, PCK, propounded by Shulman (1986) is a framework that enables examination of specialized teacher knowledge and practices that teachers use to transform their knowledge into forms that the students they teach can better understand and relate to. Mavhunga (2012) has referred to 'Topic Specific Pedagogical Content Knowledge'(TSPCK) where PCK is transformed in specific science topics for learner understanding through the consideration of five TSPCK transformation components; (i) learner prior knowledge (LPK); (ii) Curricular saliency (CS); (iii) What is difficult to teach? WID); (iv) Representations and analogies (RP) and (v) Conceptual teaching strategies (CTS). In a more recent study (Mavhunga, 2016), it has been noted that 'teachers generally transform their content knowledge through drawing interactively on other teacher *knowledge bases* to formulate effective teaching strategies (p. 2). The other *knowledge bases* referred to in the study are the five TSPCK transformation components. This study explores how practicing teachers develop TSPCK in stoichiometry through the exposure to a lesson study in the topic and how this developed TSPCK is transformed into the pedagogic practices of the teachers involved in this study.

1.2 Purpose of the research

The purpose of the study is to examine the development of TSPCK in stoichiometry of three practicing science teachers. This it does through identifying interactions of TSPCK components in the analysis of their speech and actions during planning and teaching sessions. The study further examines how the improved TSPCK can be translated into the teaching practices of the participating teachers. There is need for Science teachers to restructure the nature of their knowledge and pedagogy to suit learners in the context of their teaching. It is hoped that knowledge about TSPCK in stoichiometry will assist in fostering pedagogical transformation of content knowledge of the topic, which in turn may improve the teaching of other topics in school physical sciences. The topic stoichiometry and the mole concept , although not directly tested at grade 12, plays a very significant role in helping students answer examination questions involving the quantitative analysis of chemical phenomena. Moreover, understanding grade 12 topics such as *rates of reactions*, *chemical equilibria*, *acids and bases*, as well as *electrochemistry* is heavily reliant on the understanding of stoichiometry. There is a need to

spend more time, effort and resources in the teaching of the quantitative aspects of chemical change.

Lesson studies help teachers form forums at which they can collectively reflect on their practices. In so doing, they can keep records and databases of suggested instructional practice improvement strategies. In South Africa, the teaching of science has been perceived as inconsistent in the light of poor performance on benchmarking tests and international examinations such as the Third International Mathematics and Science Study, TIMMS (Howie, 2003; Howie and Hughes, 1998); TIMMS-R (Reddy, 2004); the Annual National Assessments (ANA's) as well as the UNESCO/UNICEF sponsored Monitoring of Learner Achievement MLA, (Mji and Makgato, 2006) program. Moreover, diagnostic reports on analyses of examination results have consistently shown poor performance in topics involving quantitative chemistry. The background to the study in the section that follows explains the need for research documenting how TSPCK develops among practicing teachers through their involvement in a lesson study. Towards the end of this first chapter, I briefly discuss the benefits of such research to the science education community and to students of science in their diverse backgrounds. The justification for doing this study follows in the next section.

1.3 Rationale

In the light of poor results especially at Matric, there is need to harness the qualities of teachers in specific topics and involve them in lesson studies for the purpose of professional development. Matric results in the physical sciences have been found to be generally poor with the majority of learners achieving very low marks, particularly in topics involving stoichiometric calculations. The table below shows physical science results between 2011 and 2014:

Table 1.1: Senior certificate Physical science results between 2011 and 2014

Year	No. Wrote	No. achieved at 30 % and Above	% achieved at 30 % and above	No achieved at 40 % and above	% achieved at 40 % and Above
2011	180 585	96 441	53,4	61 109	33.8
2012	109 918	109 918	61,3	70 076	39,1
2013	124 206	124 206	67,4	78 677	42,7
2014	103 348	103 348	61,5	62 032	36,9

Source: Diagnostic report of the 2014 National Senior Certificate Examination.

Table 1.1 shows that there has not been any significant improvement in the performance of candidates at Matric, with an average of less than 40% of the candidates getting above 40% of the marks. This shows that fewer and fewer learners obtain high percentage marks. The 30%

pass mark only shows elementary achievement obtained from the recall of facts without understanding concepts. Content transformation for conceptual understanding could lead to learner understanding of scientific concepts and improved results. A teacher planning and discussion forum in the form of a lesson study develops content knowledge of teachers, which helps to address perennial poor learner performance in physical sciences.

The world of science is both tentative and dynamic; this calls for teachers of physical science to stay abreast with technological and scientific advancements, including direct issues of content and the demands of a dynamic curriculum. Lesson studies that are geared towards improving teacher PCK and TSPCK assist teachers to develop knowledge of delivery of science content for student understanding that puts the knowledge of the teacher at the center of students' learning and success. Shulman (1986:8) states that "In order to teach science that promotes student understanding, teachers need pedagogical content knowledge, PCK". Loughran (2006) distinguishes between teaching that is aimed at delivery of content and teaching that promotes learner understanding. Understanding the transformation of TSPCK in science topics helps science teachers implement teaching strategies that promote concept understanding.

The topic stoichiometry has been chosen because it forms the baseline understanding of a number of other topics in physical sciences such as chemical equilibria, acids and bases as well as electrochemistry. There is also a need for teachers to initiate their own development programmes because when these programmes are imposed on them, teachers often resist them. This enables teachers to develop conceptual subject mastery and informed curriculum interpretation skills. Imposition of teacher development programmes has often led to high expenditure on *top-down* approaches that are of very little benefit to the teachers.

Fullan (2001) alludes to the underlying mechanism rather than surface features of instructional innovation, arguing that there is need to look deep into the ways lessons need to be improved in ways that enhance learner understanding. When teachers themselves are in charge of their own professional development, the ideas they come up with are plausible, practicable and result in conceptual understanding of subject content by learners. Involvement in a lesson study develops a sense of being in charge of one's own development as teachers come together as professionals and contribute to the planning, analysis, and evaluation of lessons conducted by colleagues. Spillane (2000) has argued, in the context of mathematics education, that hands-on mathematics, which involves written activities and discussions without reasoning through problem solving skills, may be lethal in that it does not consider the underlying mechanism that may be discussed to improve the relevance of the quality of lessons the teachers deliver. Lesson study, thus, enables teachers to willingly discuss and analyze each other's' lessons in an attempt to improve the teaching of a particular topic.

Community involvement in the work of teachers may be perceived from a sociocultural

perspective as taking views of others into consideration in teaching and learning. Other authors have referred to this form of audience as '*public research lessons' (*McLaughlin and Mitra, 2001). Such approaches enable teachers to adjust their practices to suit a variety of contextual circumstances learners find themselves in. The study generally aims to explore how practicing teachers develop topic-specific pedagogic competences and the extent to which these competences can be transferred to the practice of the classroom. The research questions that guide the collection of data in this research are discussed in the next section.

1.4 Research Questions

In the light of the purpose of the research study, to examine the development of TSPCK in practicing teachers throughout a lesson study, the following research questions were asked:

1. How does a lesson study on stoichiometry influence the development of TSPCK of three practicing teachers in the topic?

2. How does the TSPCK developed in stoichiometry, translate into practicing teachers' classroom practices?

In an attempt to answer these research questions, this study identifies interactions of TSPCK components throughout the lesson study intervention program that show the development of teachers' pedagogical content knowledge in stoichiometry. The research methodology in Chapter 3 describes in detail the means by which data were collected. To sum up the introduction to this work, I will briefly discuss the benefits of conducting such a study to the science education community.

1.5 Value of the findings to science education research

Lewis et. al. (2006) observes how lesson study results in instructional improvement through iterative cycles of improvement research (p. 3). Although most of the lesson studies that have been conducted to date are not bound to the teaching of specific topics, they show how the approach to teacher development is capable of expanding the descriptive knowledge base of an object of learning and make significant contributions towards instructional improvement. Lesson study also involves reviews of existing curricular documents, consideration for resources and the collection, presentation and discussion of collected data. All these documents are constantly read and analyzed by teachers involved in a lesson study. In a lesson study, the teachers are compelled to value their practice and to connect with colleagues who are motivated to improve. Moreover, what are strengthened during these studies are their knowledge of subject matter, their instruction, as well as the link of daily practices to long term goals. The refinement of lesson plans in the study also leads to instructional improvement.

Magnusson, Krajcik and Borko (1999) have highlighted the need to develop topic-specific PCK for all topics that are taught in science. The wide array of topics in the domain of science therefore creates a multitude of gaps in research literature for the development of TSPCK. The value of such pedagogical knowledge for research in Science education has been discussed in the purpose of the research. Chapter 2 reviews literature on both the lesson study method and misconceptions encountered in the teaching and learning of the concept of the mole.

CHAPTER TWO

2. Literature Review

2.1 Introduction

This chapter reviews literature on Pedagogical content knowledge (PCK) and its topic specific nature (TSPCK) and the relevance of both PCK and TSPCK as an analytic tool to look into teacher knowledge in science, particularly in stoichiometry and the concept of the mole. The study joins an ongoing discussion into teacher knowledge and teacher pedagogic practice; there is a need to acknowledge the proponents and forerunners of related studies to guide the current study.

2.2 Pedagogical content knowledge as a valued construct in Science Education

Teaching requires more than just the delivery of subject matter to the learners. In addition to subject matter knowledge, teachers need a special kind of knowledge to make subject matter comprehensible for the learners. Shulman (1986. p. 8) calls this kind of knowledge 'Pedagogical Content Knowledge (PCK).' Shulman refers to PCK as the integration between content knowledge and pedagogical knowledge. This means that the teachers' subject matter knowledge needs to be fused with pedagogical knowledge so that learners understand the subject matter that they teach. In science education research, pedagogical content knowledge (PCK) is a useful theoretical framework for investigating teacher knowledge (Abell, 2007). Pedagogical content knowledge embraces the teachers' subject knowledge, the teachers' understanding of the learners and the way they learn, understanding of learning contexts and other processes of pedagogy and how pedagogy can be continually comprehended in new ways. In other words, PCK is an application of subject matter knowledge so that the learner can understand it as well. When teaching practices are supported by such external goals such as those in science education reform documents that examine not only science content but also the establishment of a well-organized PCK base, they are likely to yield the desirable goal of learner achievement. The idea of PCK is further elaborated into a PCK model in other works of Shulman (1987) which incorporate Pedagogic Knowledge, Content Knowledge and Pedagogical content knowledge. There are a number of PCK models that have since emerged, each with different components (Park, Jang, Chen and Jung 2011; Loughran et al., 2006; Magnusson et al., 1999). All these models refer to PCK as a tacit construct, difficult to express and capture. In the work of Park et al. (2011), PCK can be described as planned or espoused PCK or rather as enacted PCK. Planned PCK is observable in planning documents such as lesson plans and enacted PCK may be seen in actual classroom situations. Both the planned and enacted PCK are important in studies that use PCK as an analytic lens. While for this study, both planned and enacted contexts are of interest, the focus of the study is on a specific topic, 'stoichiometry' rather than general PCK at a level of the discipline like science. Because of the narrow focus, TSPCK as a construct is relevant and plausible for answering the research questions in this study.

2.3 TSPCK as a construct in science education

Studies concerned with PCK have acknowledged and highlighted the importance of the topic specific nature of PCK (e.g. Loughran, Berry & Mulhall, 2006; Rollnick, Bennett, Rhemtula, Dharsey & Ndlovu, 2008). I adopt the Topic Specific PCK framework (Mavhunga & Rollnick, 2013) shown in Figure 2.1, where transformation of concepts within a topic is based on thinking about content through a set of specific repertoire of content specific components. Different models of PCK are employed in the studies cited above but my interest is predominantly in topic specific-PCK (TSPCK), which is related to Ball et al.'s specialized content knowledge for teaching (Ball, Thames, & Phelps, 2008):

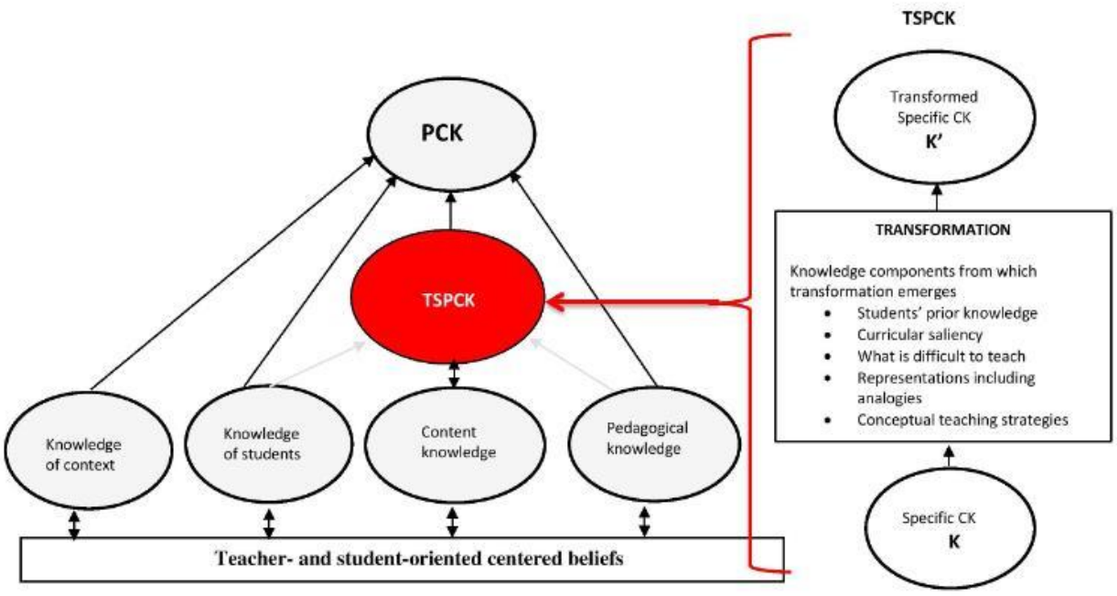


Figure 2.1: TSPCK model (Mavhunga and Rollnick, 2013)

The study takes note of the interaction of two or more of the PCK components shown on the transformation model of TSPCK. The teachers' specific content knowledge is transformed into a form that is comprehensible to the learner through the interaction of any of the components of TSPCK shown in the model. For instance, when the component learner prior knowledge (LPK) is noted together with curricular saliency (CS), this may be during observation of meetings (during the planning sessions) with teachers or during actual classroom teaching, an interaction of the two components is observed and noted as a TSPCK 'episode'. Aydin et al. (2015) have shown how findings from a similar study can be used to enumerate the number of PCK components during a lesson study in order to draw conclusions on the nature and development of interactions among components of PCK. It should be noted that the current study, unlike Aydin et al. (2015), uses a TSPCK construct with practicing teachers rather than practicum (preservice in Turkey) teachers used by Aydin et al, 2015. The research participants and contexts in this study are different.

2.4 Lesson study as vehicle for PCK development

A lesson study offers practitioners immense opportunity to be part of staff development they can own, identify with and implement with ease. Research by Lewis, Perry and Murata (2006) focuses on local innovation and research that is initiated by teachers for their own development rather than programs that are imposed on them. The lesson study teacher development approach of professional learning has spread through Japan and the United States of America. Translated from the Japanese words '*Juygun*' the (instruction, lesson or lessons) and '*Kenkuyu*' (research or study), this method advocates instructional improvement strategies that are built up from research data.

Since lesson study is a collaborative enterprise that has been used to develop teacher knowledge in many parts of the world, Nilsson (2014), working in a Swedish environment, also acknowledges that restructuring teacher knowledge and beliefs for instructional improvement is a complex challenge. Participation in a lesson study is seen as a possible means of improving science teachers' pedagogical content knowledge. Teaching is viewed as a shared practice involving collegial processes. Teachers working together with a researcher continually plan lessons together, pre-test and Post-test their learners, varying one aspect of the teaching while the other aspects remain constant, in what is termed '*variation theory*' described in lesson studies conducted by Lewis et al (2006). The teachers and the researchers then arrange Post-lesson colloquia with the aim of discussing lessons that have been taught and video recorded with the intention of improving subsequent lessons. Other researchers who have used lesson studies to

observe the nature of classroom interactions with a focus on PCK include Berry, Loughran and Van Driel, 2008; De Jong, Van Driel and Verloop, 2005 as well as Nilsson, 2014; who further distinguishes forms of professional teacher development that are done *'to and for'* the teachers against other forms of professional development which occur *'with and by'* the teachers. This study largely prioritizes teacher professional knowledge of teaching. I have discussed the lesson study approach and I find it applicable to my study because my study seeks to examine TSPCK development in practicing teachers, the use of a lesson study is appropriate since it involves the collective planning, teaching, observation and evaluation of lessons.

The study seeks to collect data that reveals the development of pedagogical content knowledge among practicing teachers. The expectation is that the joint planning, video analysis of lessons and suggestions for improvement from colleagues all lead to better performance in answering questions in a validated tool (TSPCK Achievement Tool in Appendix 1, page 79) that has been used to trace the development of TSPCK in stoichiometry. The participant teachers are required to answer questions in the tool as pre- and Post-tests which are also discussed in detail in the Methodology in Chapter 3.

2.5 CoRe as a platform for capturing developing TSPCK in a lesson study

Observation of the participants' contributions in the planning context when planning for a lesson on stoichiometry have used CoRes to take note of the way the teachers identify and use big ideas in a specific topic. Loughran et al. (2004) have used CoRes to capture and portray expert teachers PCK. Other authors have used CoRes in analyzing data collected from student teachers looking at specific topics (Mavhunga and Rollnick, 2013). In the current study, the CoRe is used as a planning document that enables participants to identify big ideas in the topic of interest, stoichiometry and the mole concept. Classroom observation tools assess teacher knowledge of teaching science through the observation of the following components in their teaching: Curricular Saliency [CS], knowledge of students or Learner Prior Knowledge [LPK]), what is difficult [WID] to teach, Representations [RP] in science and conceptual teaching strategies [CTS] for teaching science. Because the CoRes are completed during the lesson study, participants are video recorded as they complete it. A CoRe also provides an analytic lens through which this study tabulates 'big ideas' or concepts in stoichiometry. The possible difficulties with each of the big ideas are also included in the CoRe together with teaching and assessment strategies related to the topic in question. There is a need to review literature on student prior knowledge and misconceptions in stoichiometry to establish a database on common misconceptions in the topic of interest in this study, stoichiometry. The following section shows some of the literature on learning difficulties in stoichiometry that have been reviewed.

2.6 Learning difficulties in stoichiometry and the mole concept

Research on the common misconceptions among learners in the topic stoichiometry plays a significant role in elucidating the nature of learner understanding of quantitative analysis in chemistry. Malcolm et al (2014) have argued for a refined conception of the mole for the effective teaching of stoichiometry in the light there difficulties posed by the elusiveness of the concept of the mole in stoichiometry. Packer (1988) reviews difficulties in the learning of stoichiometry and alludes to the fact that there are several features of the atomic model, which make it difficult to learn. For instance, the atomic model deals with abstract concepts such as the wave-particle model and the tacit nature of atoms and molecules. It is undisputable that describing minute substances that are not tangible can be a daunting task for educators. Other authors who have looked at difficulties with science and mathematics topics include Schmidt (1987) and Cerveliati (1982). The communication of science through unfamiliar symbols and language also creates barriers especially for second language learners. An exposition of the language issues is however, beyond the scope of this writing.

Prior learner understanding is an important factor in the determination of effective teaching. Teachers need to understand their learners' prior conceptions in order to establish appropriate instructional strategies that promote effective learning. Constructivist philosophy has held that meaningful learning is based on scaffolding of relevant sets of concepts already held by the student. Cognitive psychologists (Piaget, 1896-1980) and Constructivists (Vytgosky, 1978) have maintained that prior knowledge is pre--requisite to effective learning, particularly in science. Individuals construct knowledge from experience (Hamza and Wickman, 2007; Taber, 2000*a*), and the aim of teaching is therefore, to develop knowledge that is already in the learner. The TSPCK tool in Appendix 1 has also been designed to measure the extent to which the teachers in the study solicit for prior knowledge of learners during the study.

2.7 Identifying gaps in the literature

The construct of PCK has been in existence for around three decades. Its topic specific nature has, however, recently emerged together with data that confirms the need for the integration of its components for transformation into content that learners of diverse backgrounds can be able to comprehend. The mosaic of topics in the domain of science and the existence of various educational contexts, knowledge bases, dynamic curricular as well as multiple representations all present new insights for future research. Park and Chen (2014) observe that PCK components have not been clearly explained in literature. Van Driel (2011) also notes that few studies have shown the integration of PCK components. The strength and quality of the connection between components cannot always be the same. Future research may focus on measuring and quantifying the strength of TSPCK episodes that depend on the context from which a particular episode is drawn. Similar instruments may be developed to enable PCK to be captured within the context of the classroom. Research has already begun in South Africa and elsewhere to establish the transferability of pedagogic competences learnt in one topic to other topics in chemistry (Mavhunga, 2016). Having identified relevant literature and gaps therein, I will describe, in the next chapter the methodology used in seeking answers to the research questions in this study.

2.8 Conclusion

Literature on PCK and TSPCK is not new in science education research; this study therefore joins an ongoing discussion into the pedagogic practices of science teachers in stoichiometry. This chapter stresses the need for the review of related literature which ranges from considerations of relating PCK to TSPCK; the relevance of these constructs to science education research; how valuable they are in science education as well as in science education research. Relevant literature has also included a search for common misconceptions and difficulties encountered by learners as they try to understand chemistry in general and stoichiometry in particular. The reviewed sources have enabled the identification of gaps in the literature, for instance, the design and validation of tools that can be used to measure TSPCK in the context of classroom practice.

CHAPTER THREE

3. Methodology

3.1 Introduction

This chapter describes the methodology followed in the study to find appropriate ways of answering the questions raised in this research. All relevant sources of data are listed and discussed. This chapter goes on to describe the case study approach used as well as a rationale for using the case study. In addition, this chapter describes the qualitative approach used to analyze data that were obtained. This chapter closes by looking at the ways that the data will be analyzed with considerations to the trustworthy and validity of the instruments used in collecting the data.

3.2 Overview of the methodology

In the previous chapter, I reviewed literature on the development of professional teacher knowledge in practicing teachers using a lesson study. I argued for the exploration of the development of TSPCK in specific topics, particularly, in stoichiometry. I further used the review of literature in Chapter 2 to support the purpose of the study expressed through the following research questions:

i. How does a lesson study on stoichiometry influence the development of TSPCK of three practicing teachers?
ii. How does the TSPCK developed in stoichiometry, translate into practicing teachers' classroom practices?

In this chapter I discuss the research design used to elicit answers to the listed research questions. I start by describing the research method used to show the development of TSPCK amongst three practicing teachers in the light that PCK is a tacit construct that is difficult to measure, impossible to see, touch or capture. The study's research methods build on literature and research tools that show us how this construct develops. The data is collected in the form of video recordings of pre-lesson discussions, recordings of actual lessons and Post-lesson discussions. This chapter is concluded by showing how the data collected from the sources mentioned above is analyzed for pedagogical content knowledge, developing TSPCK, and shifts in the quality of TSPCK both before and after the interventions, as well as the demonstration of TSPCK in classroom practice.

3.3 Research Design

This study employs a 'basic qualitative study design' (Park and Chen, 2012; Merriam, 1998: 11) to investigate the development of TSPCK among practicing teachers who have been exposed to a lesson study on the specific topic, stoichiometry. The qualitative research design involves the collection of qualitative data or non-numerical data in the form of words or pictures. Some researchers have used qualitative research methods in the investigations relating to teacher learning "because we were interested in teacher learning, we used qualitative case study methodology to investigate 'how' and 'why' questions, which seek to make sense of the operational links individuals make over time, rather than at a single incidence' (Stake, 2005; Yin, 1994). Qualitative data follows an explanatory approach and paradigm characteristics that use narratives to examine human behavior and choices as they occur naturally. A 'bottom-up' approach is used in qualitative research to explore the subjects, enabling the researcher to generate and construct knowledge and draw hypothesis from data that is grounded in the collection of data from fieldwork rather than confirmation of set hypothesis in the case of

quantitative or mixed methods research. Since a complex phenomenon, '*teacher knowledge'* is being investigated, it is imperative to consider the use of qualitative methods to answer the research questions that take into consideration different contextual circumstances in the teaching and learning of specific topics. Moreover, human behavior, actions and choices cannot be easily quantified and the small sample size makes the use of quantitative methods to be inappropriate for this study. Explanatory approaches enable the qualitative researcher to 'get close' to their object of study by observation of the participants, enabling researchers to gain subjective dimensions of the phenomenon that they are studying. The qualitative researcher asks questions prior to the collection of data, makes interpretations and goes on to record what is observed as opposed to the reliance on measuring devices and instruments that are standardized because human behavior and actions cannot be easily statistically quantified under natural settings but could be placed into categories. Quantitative researchers have also assumed that cognition and behavior are predictable and explainable (Salmon, 2007). However, qualitative researchers on the other hand seek to understand people that they observe and report their findings from the 'participants', 'native' or 'actors' points of view. Weber (1968) agrees with this assertion in referring to '*verstehen'* which is described as the idea of understanding something from another person's viewpoint. Qualitative data documents what was done, where it was done and why it is done. The qualitative researcher tends to put him or herself into the 'shoes' of the participants in an attempt to get an insiders' perspective of the issue that is being studied. Qualitative researches help provide a practicable way to answers complex research questions in humanities which cannot be numerically generalized and deduced. Lincoln & Guba (1985) accepted that qualitative researchers generally contend that reality is socially constructed. Social issues are subjective, involving multiple factors affecting the interactions of teachers in this study who discuss how stoichiometry can be taught for conceptual understanding. This illuminates the need to organize relevant lesson studies for target teacher professional growth development programs. Although some aspects of the data have been analyzed using statistical averages only, the sample size fell off the quantitative research paradigm since most of the data required descriptive and interpretive patterns. Qualitative data is usually gathered from a few individuals or cases, its findings and outcomes cannot be spread to larger populations; however, they are transferable to other settings. Social interactions are a more complex phenomenon that can hardly be summarized using only numerically ascribed values. The following bullets list and summarize the distinct benefits of using qualitative research methods:

- Examines human behavior and choices in all its detail as it occurs naturally
- Qualitative researchers avoid interventions in the natural flow of behavior and events
- Multiple constructions are brought into play (Moran and Butler, 2001)
- Enables an exploratory bottom-up approach that constructs knowledge from grounded theory
- Hypothesis are generated from data obtained during fieldwork
- Qualitative research tries to naturally and holistically understand multiple dimensions and layers of reality such as types of people in a group, how they think and interact, and the kinds of norms and agreements they have.

In this study, qualitative data is collected in the form of a TSPCK achievement tool (Appendix 1), which consists of multiple choice and open ended questions administered to the practicing teachers before and after the lesson study treatment as well as several discussion, planning and lesson evaluation sessions focusing on the topic stoichiometry. A TSPCK rubric (Appendix 2) is also used to assess the interactive use and development of TSPCK during the lesson study. Although the learners were also given pre- and Post-tests before and after they were taught by

each of the participants in order to reveal the impact of teacher treatment on learner achievement, the findings from this part of the study have not been reported since the scope of this study focuses only on the TSPCK development of teachers, not the learners. The impact of lesson studies on learner achievement leaves room for further research into how TSPCK impacts on the learning of stoichiometry or any other science topics. The frequency of TSPCK component use and contributions related to the concept of the 'mole' are observed in the pre-lesson discussions, during classroom teaching as well as in the Post-lesson colloquia. The TSPCK components are noted as they interact during participant teachers' discussions with science teacher educators, science education researchers and during lessons with the learners they teach in science classes. These were all enumerated in the analyzed video recordings that informed the research on how teacher TSPCK in stoichiometry improves because of their involvement in a lesson study. The next section briefly discusses the research strategy employed in this study.

3.4 Research Strategy-case study

This research employs a case study approach, which is a form of qualitative research that is focused on providing a detailed account of one or more cases. Case studies rely on qualitative data; the use of a number of strategies in case studies can reveal more information about the case being studied, teacher pedagogical knowledge in this case. Stake (1995) and Yin (1994) posit that case studies are used to address *exploratory, descriptive* and *explanatory* research questions. Analysis of four verbatim transcriptions of the planning sessions is a form of the qualitative data in this study. Teachers also responded to the stoichiometry achievement tool in an attempt to determine their conceptions of the mole and how it is taught in the 11th Grade; their responses constitute qualitative data obtained from the lesson study. In the collection of qualitative data, an exploratory mode of collecting information is used. Data is collected from discussions and natural classroom setting, since each of the teachers taught the lesson on stoichiometry in their own schools. This qualitative form of research referred to as a case study, involves studying a case of three practicing teachers, each of the three practicing teachers also form separate 'cases' or units of analysis when they teach the lesson on stoichiometry in their different schools. The advantages of a case study over other qualitative methods for this research are that it is more varied than phenomenology, which focuses on experiences of individuals; ethnography relates to aspects of culture and will involve the researcher going into the field and thereby interfering with the natural flow of participant behavior. A grounded theory focuses on the development of explanatory theorems. In a case study, each case is focused on as a whole unit as it exists in its real life context. Akinyemi (2016) states that 'employing a case study as a strategy in this study helped in conducting an extensive and in depth investigation of; how pre-service teachers develop PCK in the topic of intervention' (p. 36). Although the author examined TSPCK development in a different topic (Kinematics, a physics topic) and with pre-service teachers, the common need for a detailed account of human experiences has necessitated the use of case study approach in the current study involving experienced teachers in a chemistry topic: stoichiometry. Another example of a case study has looked at the journey' through college of seven gifted learners and the influences on their career related decisions (Grant, 2000). The author went on to analyze each case and made cross-case comparisons, identifying similarities and differences. The current study uses a similar approach that involves three cases of practicing teachers, teaching in contexts that are more or less similar but in different schools. The pre- and Post-lesson video recordings and actual classroom teaching videos are also a vital source of qualitative data that provided a detailed account of each of the three cases and how similarities and differences emerge in the way in which planned TSPCK is developed and transformed into classroom contexts. The trajectories of TSPCK development of three teachers during the lesson study spanning five weeks, on a single topic taught over three lessons in three separate cases is used to obtain data on TSPCK development. Each of the three teachers' form a separate unit of analysis in this case study.

3.5 Participants

The participants in this study were three practicing science teachers. The research used practicing teachers with various teaching experiences that range between 6 and 18 years including me, the researcher. All three participants voluntarily participated in the study; they are all postgraduate students focusing on PCK in a similar programme to the researcher's; what is common about the three is that they are practicing teachers. The researcher is one of the participants in the study, his role involves both the collection of data as well as being a participant practicing teacher himself; all three participant teachers are male. The focus has been on identifying their contributions and relating these to their pedagogical classroom practices. Table 3.1 summarizes the profiles of the three teachers used to obtain data in this study; their qualifications, teaching experiences and the number of years they have been teaching grades 11 and 12 physical sciences. The practicing teachers are teacher-researchers in science education who are conducting part-time research on other aspects of PCK. There was no sampling criterion in the selection of these participants as they voluntarily participated in the study.

Table 3.1 Teaching qualifications and experiences of the participant practicing teachers.

Teacher	Qualifications	No. of years in teaching	No. of years teaching grade 11 and/ or 12
1 (Andy)	BSc (Hons)	6	6
2 (Alex)	Hons in Physics	19	6
3 (Gigi)	Hons B.Ed.	11	5

Each of the participants attended all the four planning sessions during the lesson study. In addition, each of the participating teachers taught a one-and-a half hour (90 minutes) lesson on the mole concept of stoichiometry in their respective schools. Both the lessons and discussion sessions were all video recorded. The learners they taught from each of the schools were all grade 11 boys and girls aged between 16 and 19 years of age. One of the schools is a former Model C (teacher Alex), formerly characterized by learners from higher socio-economic status. The other two are township schools with learners from generally low-income families with different language and cultural family backgrounds. Teacher Alex teaches in Alexander Township in the greater Johannesburg North District whereas both teacher Andy and Gigi teach in the Kagiso townships in Gauteng West District. The first lesson, which served as an exemplar lesson, is taught by an experienced science teacher prior to the teaching of the three participants. All three participating teachers have postgraduate qualifications in the teaching of secondary school science. The lesson study intervention is considered to be a form of treatment that the three practicing teachers undergo in the way they engage regularly with teacher educators on TSPCK components and how they are integrated into the teaching of stoichiometry. The following section describes the treatment that the participants went through during the lesson study.

3.6 Treatment- Intervention to developing TSPCK

The lesson study intervention had four cycles of discussion and planning meetings that I regard as the treatment in this study. The discussions in these meetings focused on instructional improvement strategies that are built up from research data and the collaborations of teachers, teacher educators and researchers involved in this study. The interventions went on for five weeks during which planning sessions took place once every week, on an agreed upon weekday. A colleague who was not part of the study recorded all four videos of the planning sessions. As a researcher who was also involved in the study and aware that I would be reporting on this

study, I had to delegate the task of video recording in order to focus on the discussions and participate freely. The general structure of each meeting session started with the lead researcher who was the most experienced educator in the project welcoming all and explaining the purpose of the meeting. Usually, other than the first meeting, the participants would have received, prior to the meeting, a video recording of the lesson recorded in a class taught by one of the participating teachers. The first 20 minutes were open discussions of the video and comments by participants. The practicing teachers were encouraged to state their views and critique recorded lessons. The next 20 minutes were spent planning and refining the lesson plan for the next round of teaching and lesson analysis. The last 10 minutes were used to discuss and confirm logistics of dates, recording and reminders for the times and venues for the delivery of the refined lesson plan and dates for the next meeting were communicated. The focus in each of the discussion sessions is summarized in Table 3.2.

Table 3.2: The structure of discussion sessions in the lesson study

Planning session	Focus of session	Duration
1	• Discussion of sample lesson video • Planning for first lesson • Discussion of CoRe'	+/- 90 minutes
2	• Discussion of first lesson and comments by Participants • Planning and refining of lesson plan • Logistics for the next meeting	+/- 90 minutes
3	• Discussion of second lesson and comments by participants • Planning and refining of lesson plan • Alternative sequencing of activities	+/- 90 minutes
4	• Discussion of third lesson and comments by Participants • Summarizing the data collected • Causes of disparities in pre- and Post-test results	+/- 90 minutes

As the nature of a lesson study requires practicing in a form of teaching of the discussed lesson plan, lessons were taught on Saturdays where the practicing teachers delivered lessons planned from the meetings in their respective schools. Although data were collected from the lessons, this part of the data collection is not part of treatment as no support was provided to the teachers during delivery of their respective lessons. However, the number of times each of the participants is exposed to discussion sessions at the time of going to teach was not the same. Teacher Andy taught first after only having been exposed to only one discussion meeting. Teacher Alex had been exposed to two discussion meetings at the time of going to teach whereas teacher Gigi had been exposed to all three planning sessions at the time of going to teach. The number of times each of the participants is exposed to discussions at the time of going to teach is considered when the findings of this study are analyzed in Chapter 5. Table 3.3 presents the different times at which teaching happened during the intervention.

Table 3.3: Schedule for treatment and classroom teaching.

Teacher	Number of meetings before teaching	Classroom teaching	Exposure to treatment after Teaching
Andy	1 meeting	Between meetings 1 and 2	3 meetings
Alex	2 meetings	Between meeting 2 and 3	2 meetings
Gigi	3 meetings	Between meetings 3 and 4	1 meeting

The lessons were not all taught at the same time, this staggered teaching provided the researcher an opportunity to look into the impact of the treatment at different times of the intervention in a way that shows, for instance that teacher Andy had the least number of intervention meetings before his lesson, relating this to the number of TSPCK components used in his classroom provides qualitative data about the development of TSPCK. Such data serves to assess the impact of the lesson study interventions on each of the participants. In the following section, I discuss the way in which the data in the study is collected and organized for analysis.

3.7 Data collection

The TSPCK tool is used as the first source of qualitative data. The observation of enacted TSPCK in the classroom videos as well as the development and use of the rubric for the assessment of enacted TSPCK in the classroom (Chapter 4), both determine the quality and strength of TSPCK episodes all observed during classroom teaching. All these are considered to be sources of qualitative data in the lesson study on stoichiometry and the concept of the mole.

Different tools/instruments are used in the collection of data in this research with each tool yielding qualitative data. There are situations where analysis of each tool/instrument uses qualitative means to obtain as much information as possible and not to miss any aspect of the data. For instance, the TSPCK tool was qualitatively analyzed by categorizing each of the episodes observed in teaching as either "Basic, Moderate or Sophisticated" TSPCK episodes. Interactions forming TSPCK episodes whose content can be further analyzed qualitatively depending on whether there is an integration of different components or a component is repeated within an episode. Table 3.4 summarizes the instruments that were used to collect the data, showing how each of the instruments was analyzed. The table also shows that all the instruments used were sources of qualitative data in the last column.

Table 3.4: Summary of how data was collected during the lesson study

Stage	Instrument/Other means	Type of data collected
At the beginning of the intervention: Pre-test	Stoichiometry TSPCK Achievement tool	Qualitative data
At the end of the intervention: Post-test.	Stoichiometry TSPCK Achievement tool	Qualitative data
During the intervention/treatment (Video recordings).	TSPCK rubric	Qualitative data
In classroom practice	Rubric for enacted TSPCK	Qualitative data

3.8 Analysis of data

In this study, as indicated before, I was one of the three practicing teacher participants. The dual role as both a participant and a researcher, of which I am aware, will limit any researchers' ability to observe according to Tabach, 2011. In order to minimize my personal influence on the findings from the data collected and analyzed, I have observed a few strategies:

- I used an independent person to collect data through video recordings of all the meeting sessions including classroom observations.
- I used an independent rater, in addition to my scoring, in the scoring of the completed tools and identification of the TSPCK components in the recorded videos.

As mentioned in the introduction, the study has interest in the impact of the intervention on Topic Specific Pedagogical Content Knowledge (TSPCK) of the science teachers who participated in the lesson study. The purpose of the study is to examine how TSPCK develops in stoichiometry in practicing science teachers through interactions with each other and with science teacher education experts in the context of a lesson study. Furthermore, the study had interest in examining how the newly developed TSPCK is translated into the teaching practices of the participating teachers. The need for science teachers to restructure the nature of their knowledge and pedagogy to suit learners in the context of their teaching has been emphasized throughout the study and in PCK literature (Shulman, 1986). The PCK and TSPCK analytic tool was employed as it fosters pedagogical transformation of content knowledge of a topic (Mavhunga and Rollnick, 2013); which in turn improves the teaching of the topic in school physical sciences.

The data used to analyze each of the aspects of the study were drawn from the various sources shown in Table 3.3. In the following paragraphs, I indicate how the data will be analyzed from each instrument.

To analyze espoused or planned TSPCK using the TSPCK achievement tool, the TSPCK rubric (Appendix 2) is used to obtain TSPCK scores for each of the participating teachers using the validated TSPCK rubric. The rubric has 5 rows with each of the TSPCK components against scores in the columns 1 to 4 that show TSPCK scores that range from Limited TSPCK (score 1); Basic (score 2); Developing (score 3) and lastly Exemplary TSPCK with a score of 4. Although the tool is validated, an independent rater is used to confirm the test scores. The pre- and Post-test results are then compared to find similarities and differences and to show shifts, if any, in the scores from pre- to Post-test. The pre-test is administered prior to the intervention and the Post-test is written immediately after the fourth meeting in the lesson study. The test scores are then individually analyzed and generalized using mathematical averages.

For analysis of developing TSPCK during the intervention, the number of TSPCK components in the verbatim transcriptions of each of the three practicing teachers during treatment is used. Not only are the TSPCK components identified but also the nature of these interactions is analyzed. Where two or more TSPCK components interacted, a TSPCK '*episode*' is formed. The existence of TSPCK components in each of the participant teachers' speech during the four discussion and planning meetings is analyzed. The evident TSPCK components and the nature of their interactions are a valuable source of data that show developing TSPCK. For each of the participants, the frequencies of contributions related to the mole during meetings are recorded. The number of times each participant is exposed to treatment is analyzed against the number components of TSPCK observed in their teaching.

For analysis of the shifts in the quality of TSPCK before and after the intervention, the TSPCK scores of each participant were summed up and generalized using mathematical averages to compare scores prior to the treatment and scores after the treatment. In the interactions of

components, the quality of each interaction of two or more components is also analyzed, creating qualitative data that tends to explore how rich episodes relate to effective science instruction that leads to enhanced learner performance in science.

For demonstration of TSPCK in classroom practice, analysis of teacher talk and gestures during the teaching of stoichiometry in class is analyzed for the presence of any TSPCK component interactions. A rubric, developed in this study in Chapter 4 is used to place the interacting components of the participants into three categories (Table 4.9, p. 32) in the lessons they taught on stoichiometry (considered to be *enacted* TSPCK) during the intervention. For each of the participants, the number of TSCPK components in their teaching of the lesson is analyzed against the number of times they had been exposed to treatment at the time of teaching. Group mathematical averages for pre- and Post-tests were compared to validate the overall findings of the study.

3.9 Context

There are four planning sessions in total, each with a duration of about 1 ½ hours (90 minutes) making a total of six (6) hours (540 minutes) in planning sessions that are video recorded and transcribed for verbatim analysis. The other data sources are the videos recorded in the classroom teaching (enacted TSPCK) of the same teachers as an intervention that is constantly improved prior to the teaching by the next teacher in the study. The three lessons, with a duration of about $1\frac{1}{3}\ hours$ each on average (80 minutes), had a total duration of about four hours (320 minutes). Controlled pre- and Post-tests administered to the learners assisted in determining the outcomes of the interventions in terms of learner performance before and after each of the lessons. However, the learner results are not to be analyzed in this study because the focus is specifically on teacher TSPCK development. The recording of videos allowed the researchers to replay the videos during analysis in an attempt to capture and record components of TSPCK, the interactions of these components, as well as the determination of the quality of each interaction in explaining a concept or a set of related concepts.

The questions in the TSPCK achievement tool were designed to find out from the teachers if they were familiar with the concept of the mole and how it can be best taught at Grade 11 through the integrative transformation of TSPCK components; familiarity with the components of TSPCK; their use of curricular documents and any conceptual teaching strategies that they might have used before, during and after their involvement in the lesson study. All lesson plans are jointly prepared for by the participating teachers and science education researchers involved in this study. This enables the sharing of ideas and iterative discussions that are aimed at consistently improving the delivery of the same lesson for conceptual understanding.

3.10 Sources of data, validity, reliability and ethical considerations

The first data source made use of the TSPCK achievement tool scores. During the discussion sessions, the researcher looked for evidence of developing TSPCK in teacher talk in all sessions of the lesson study discussion meetings and in the lessons that each of the participants taught. The transcriptions of words spoken by the teachers involved in the study, which were analyzed for TSPCK components, their interactions, as well as the quality of these interactions during the entire lesson study. The TSPCK tool provides qualitative data as the participants respond to open ended questions with subjective interpretations.

Trustworthiness in qualitative analysis

Analysis of the TSPCK tool is meant to bring about findings that are of a qualitative nature through finding evidence of TSPCK component interplay during the lesson study intervention programme. In the paragraphs below, I discuss how this qualitative study will ensure not only

trustworthiness of the findings, but also their credibility, transferability to other research contexts and cases, dependability and confirmability of the findings. The section outlines the individual issues of research rigor that have been used in this study to make sure that the study is conducted in a neutral way that will address concerns of consistency of the findings in the light of the following questions listed by Dey (1993) to keep checks on the quality of data:

- ✓ Are the data based on your own observations or is it hearsay?
- ✓ Is there corroboration by others of your observations?
- ✓ In what circumstances was an observation made or reported?
- ✓ How reliable are the people providing the data?
- ✓ What motivations might have influenced a participants' report
- ✓ What biases might have influenced how an observation was made or reported?

All these questions, when appropriately answered, relate well to the *validity and reliability* (although these terms are often associated with quantitative research) of the data collected in this study, relating to the quality of rigor (how valid and reliable the qualitative data is) with which the data is collected and analyzed. Each of the qualitative terms that relate to research rigor is discussed below.

Credibility. This relates to truthfulness and accuracy of research findings. Hammersley (1992) has noted that "...an account is valid or true if it represents accurately those features of the phenomenon that it is intended to describe, explain or theorize."(p. 69). The study examines the development of TSPCK among practicing teachers including the transfer of competences developed during a lesson study to the classroom practices of the teachers involved in the study. To report what actually occurs in the field, the study uses video recordings of meetings of teachers and teacher-education researchers in finding TSPCK component interactions in the verbatim transcriptions of the meeting videos as the lesson study intervention progressed. In this way, the study reports the actual findings from what was actually said and done by the teachers during the lesson study. Krefting (1991: 215) made similar suggestions about the credibility of a qualitative study, by stating that a qualitative study is credible when "it presents such accurate descriptions or interpretations of human experience that people who share that experience would immediately recognize the description." A true account of the proceedings in data collection and reporting is ensured in this work through the researchers' obligation to show the realities of the research participants as accurately as possible. The case study and document analysis enables corroboration of qualitative findings, this helps to create better evidence, especially when the different data sources are in agreement, when major themes converge and phenomenon is understood from different viewpoints, and findings are likely to be credible and internally valid. Other methods of ensuring internal validity of findings range from creation of evidence for consensus in findings (including peer review and peer debriefing); adequacy of participant reference and researcher interpretation (Johnson & Christiansen, 2000); as well as evidence of theoretical adequacy and plausibility where the explanations from the study fit into the data and is defensible. Extended fieldwork, theory triangulation and pattern matching are also mentioned in Johnson and Christiansen as other ways of enhancing data credibility.

Transferability. This refers to the extent to which findings from qualitative studies can be generalized or applied to other contexts and groups. In quantitative research, this however is referred to as *external validity*. A rich, detailed and thick description enables other groups to relate well to findings of a qualitative study. In this way, comparisons can be made; resulting in judgements that reveal similarity and therefore, transferability is possible due to the adequacy of descriptions. The qualitative methods used in this research were previously used to capture episodes of PCK (Park and Chen, 2012) in the teaching of the topics *electromagnetism* and *chemical energy and change* in separate studies to make sure that the methodology was not adapted only for this study; more recently in the works of Akinyemi (2016) in the physics topic, *kinematics*. This is evidence that the research strategy has been used in other previous studies. It

is hoped that the methodology used here would be used in other studies that investigate the development of TSPCK using either practicum teachers (teachers in training) or in-service (practicing) teachers both in planning sessions (espoused TSPCK) and in classroom settings (enacted TSPCK). Criteria for observing the development of TSPCK in a lesson study and in classroom contexts was captured in the rubric designed specifically for capturing enacted TSPCK that is discussed in chapter 4. The next paragraph explains the dependability of the qualitative approach used in this study.

Dependability. This describes the extent to which data and findings would be similar when the study is replicated. However, contexts of studies are not always the same, strategies may also be changed. The use of audit trail, logical replication of the study, coding and re-coding, inter-rater reliability (coding agreements) in rubric analysis and triangulation all relate to strategies that ensure the dependability of data and findings. Other researchers will be able to design criteria for categorizing the interactions of TSPCK components from other studies by making use of the rubric used in this study to categorize TSPCK interactions in contexts and cases other than the one found in the methodology for this research. The clear procedure laid out in the rubric was agreed upon by the researcher, a colleague focusing of TSPCK studies, as well as confirmation by a teacher education researcher. It is also hoped that similar findings may be obtained when this qualitative tool is used in other studies.

Confirmability. This refers to the neutrality or the extent to which the research is procedurally free of bias, the interpretation of results also needs to be free of bias to the extent that these can be used by others who investigate similar situations. My supervisor and I will safely keep the recorded videos and raw data in the form of assessed rubrics and instruments completed by the participants and interpretations of rater opinions. The TSPCK tool, a validated tool has been used in previous studies in other topics such as kinematics (Akinyemi, 2016); redox reactions and electrochemistry (Aydin and Boz, 2013); chemical change; acids and bases; the mole concept (Fang et. al, 2013); chemical equilibria (Mavhunga and Rollnick, 2012) among other studies. The findings of the research are not in any way influenced by the researcher. Daniel & Onwuegbuzie suggests that the following questions be asked to make sure that there is confirmability of the research procedures and findings:

- ✓ Is cohesiveness of evidence shown?
- ✓ Have the inconsistencies of the data been examined?
- ✓ Have alternative explanations been considered?
- ✓ Are there sureties?
- ✓ Does the researcher have confidence in the results?
- ✓ Has the elusive goal of data collection been achieved?
- ✓ Is there adequacy of evidence?

Since the study employs qualitative research methods, there is a need to ascertain the trustworthiness of the findings. In answering research questions about social issues, the use of integrated qualitative methods is considered pragmatic in the works of Tashakkori and Teddie (2003), although other researchers suggest that differences between qualitative and quantitative paradigms are illusory (Coxon, 2005; Howe 1998; Pawson, 1995).

Teacher knowledge remains a social issue in the sense that education is a societal concern; therefore, there is a need for research methods and analysis techniques that relate to social research procedures. There is no doubt that participant perspectives are of paramount importance and can bring the most out of complex social research matters. The next chapter focuses on the development of a rubric that was suitable for enumerating TSPCK episodes in the context of classroom practice (enacted TSPCK) as well as determination of episode strengths, quality and effectiveness in the teaching of science in general and the mole concept in particular.

3.11 Conclusion

An account of the methodological processes involved in gathering data for this study is given in this chapter. The justification of the use of a qualitative design to answer research questions in education, the use of a case study approach as a research strategy over other qualitative research methods is explained in this chapter. There are also discussions on the techniques to be employed in analyzing the findings of this study with due considerations to research ethics and ensuring the findings are both valid and reliable. There is a need to design a rubric to measure TSPCK development in the context of classroom teaching as no such rubric has been found in the literature reviewed in chapter 2. The next chapter shows how such a rubric is designed in order to measure TSPCK in the practice of teaching different topics in science.

CHAPTER FOUR

4. THE DEVELOPMENT OF A RUBRIC FOR EVALUATING ENACTED PCK

4.1 Introduction

As indicated in the previous Chapter, this study examined the impact of a lesson study intervention on the quality of TSPCK demonstrated in teaching the stoichiometry concept of the mole by the participating teachers in this study. In order to grade the quality of TSPCK observed in classroom practice, a rubric is needed. In this chapter, I first provide the rationale for a separate rubric for enacted PCK, explaining why the existing rubric for planned TSPCK has been considered inadequate for this task. I then outline the process followed to develop and pilot a rubric in science lessons taught by practicing teachers who were not involved in the current lesson study. I close by presenting the emergent rubric.

4.2 Rationale for a rubric to grade the quality of enacted TSPCK

Enacted TSPCK refers to TSPCK observed in the actual process of teaching a specific topic to learners. It is different from planned TSPCK which is observed from planning contexts reflecting mostly the reasoning that prevails (Aydeniz and Kirbulut, 2014). It is however, important to notice that the difference between the two is merely an issue of the context in which TSPCK is observed. The context in which TSPCK is observed does not change the definition of what TSPCK is but acknowledges the different formats in which it manifests itself. Furthermore, it is important to recall that Shulman (1987) argued for the importance of both planned and enacted of PCK. While it is common practice to use existing tools that have been validated and used in other empirical studies, there however, is paucity in the literature on rubrics that are designed to grade the quality of TSPCK component interactions observed in classroom settings. Rollnick and Mavhunga (2013) developed and used a TSPCK rubric to evaluate the responses of pre-service teachers captured in a TSPCK tool on chemical equilibria. While generic in nature, this rubric is however, not completely suitable for the context of my study that examines the quality of TSPCK in action; enacted during classroom lessons. The key difference, in my view, between the two types of TSPCK is that planned TSPCK can be prompted by instruments such as in the CoRe's (Loughran, et al., 2004) or test items in a specially designed tool, whereas enacted TSPCK naturally occurs as the lesson and the events unfold in a classroom. Furthermore, the sequence and the use of the specific TSPCK components cannot be preset as in a TSPCK tool. However, common across the two types of TSPCK rubrics is the agreement on the need for evidence for interaction of the components. As with PCK, component interaction is also important in TSPCK. Aydin and Boz (2013) have argued that for successful teaching to occur, the integration among the components of PCK is essential. This means that individual or isolated components of PCK and consequently, TSPCK, will

not result in effective teaching. Thus, teaching segments that demonstrate the interaction of two or more TSPCK components are referred to as TSPCK 'episodes' after Park and Chen (2012), who has defined a PCK episode in a similar way.

The mere identification of components of TSPCK in teaching without them interacting does not translate to a sophisticated TSPCK that can lead to enhanced learner understanding. To show the importance of the interaction of components, researchers have used a number of labels such as interplay (Park and Chen, 2012); integration (Friedrichson et al., 2009); interrelationships (Kaya, 2009); coherence (Magnusson et al. 1999); intersection (Fernandez, Balboa and Stiehl (1995); interaction (Cochran et al., 1991) among other terms. Grossman (1990:9) has been among the first scholars to consider interaction among knowledge components. Grossman observes that '…these components are less distinct in practice than in theory.' This means that the components interact in more complex ways than the unidirectional interactions in the analysis done by Aydin and Boz (2013). In their study, they also used the conception of a PCK episode similar to Park and Chen (2012). They developed a scoring rubric in which PCK component interactions were graded based on frequency between the interactions of two components. The challenge with this method is that it is not able to describe sophistication of the interactions because of interaction of more than two components at a time. It also assumes a linear interaction and it does not depict even pictorially how the components interact. It could not be worked out in their approach for example, how far or how close the components are to each other and their sequencing. For these reasons, there was need for a rubric that captures these aspects.

4.3 Developing a rubric for grading TSPCK episodes in the practice of teaching science

The classroom teaching of two experienced practicing teachers is observed with a purpose to capture and study the various TSPCK episodes as they occurred. Experienced teachers were used because PCK is a germane of teachers with experience and this study has interest in seeing the various possible TSPCK episodes in action. Shulman also observed expert teachers in order to establish the process of pedagogical reasoning (Shulman, 1987). The practicing teachers observed in this chapter had been teaching these topics for a period of at least 4 years and were considered effective and knowledgeable in the subject by their peer teachers in their respective schools. Moreover, both teachers are also involved in lesson studies and video recording of their lessons; they are also willing that their lessons be shared with other teachers to improve the teaching of science through constructive criticism of the lessons. The lessons are an opportunity for the researcher to pilot a rubric for grading episodes of TSPCK in the practice of teaching. The two teachers who were used to pilot this rubric when it was developed taught in former Model C Schools, commonly characterized by reasonable level of good school governance and class management. The students in these schools were largely from previously disadvantaged community groups who desired good quality education for their children. It is quite common to have learners commuting daily from distant residential places to attend these schools. Table 4.1 summarizes the biographical details of the two teachers and the topics for which their teaching is observed. The table also shows the qualifications of the two teachers, the kind of schools in which they teach and the

number of lessons that were observed as well as the duration of each of the lessons in minutes.

Table 4.1: Biographical information of practicing teachers in the pilot study

Name of Teacher	Qualification and experience in practice	Topic	School	Grades	No of lessons video recorded	Duration per lesson
*Liso	B. ED and 4 years	Chemical Energy and Change	Ex-Model C	11	2	35 Minutes
*Qondi	B. Ed and 5 years	Electromagnetism	Ex-Model C	11	2	35 Minutes

** Pseudonyms have been used to identify the participating teachers*

The two teachers, Liso and Qondi are both progressive teachers who have agreed to the use of the videos of their lessons in educational research in general and in lesson studies in particular to enable informed reflections into their practices. Each of them taught two lessons of 35 minutes each; all four lessons were video recorded. Both teachers taught their topic to Grade 11 learners. The choice of the topic was dependent on the topic the teacher was teaching at the time of the visit. The criterion was that the topic needed to be in the Further Education and Training (FET) phase as the topic of stoichiometry investigated in this present study is taught at this phase. The analysis of the video-recorded lessons happened in two phases. The first phase was the identification phase and the second phase the categorization phase. TSPCK episodes are identified and categorized according to their content, which is analyzed for TSPCK components and in relation to the concept of the mole. A brief description of the content analysis is shown in the next paragraph.

In the identification phase, the first step in the analysis of the video-recorded lessons was what Aydin and Boz (2013) refer to as *manifest content analysis.* This step required the content analysis of the video-recorded lessons for the presence of TSPCK episodes. An operational definition of a 'TSPCK episode', referring to a teaching segment that demonstrates the use of two or more TSPCK components, is used. Myself and two other science education researchers whose research activities are in the field of TSPCK analyzed the videos together, identifying TSPCK episodes within the four lessons and reaching a consensus upon agreement that an episode has been identified on any one segment of a lesson. The two researchers are familiar with the idea of TSPCK episodes. The identified TSPCK episodes were then confirmed through discussion when the consensus was reached, the episode is noted. To capture the information in the videos, the videos were played at 5-minute intervals as the lesson was analyzed and an agreement is reached between the researchers regarding the identification of evident components of TSPCK from the video segments. The second phase entailed analysis of the identified TSPCK episodes for common patterns either by the number of the interacting TSPCK components and/or by the

evidence for the manner or sequence in which the interaction happens. The identified patterns in TSPCK episodes were then represented through a TSPCK map. A TSPCK Map is a pictorial representation of components of TSPCK that are interacting. I went on to draw the TSPCK maps of the agreed upon episodes and will discuss them in this chapter (see Tables 4.4 - 4.9). The PCK map is also an idea that has been used by Park and Chen (2012) in presenting PCK episodes identified in their study examining PCK episodes in the lessons of two practicing Life science (Biology) teachers. The last step involved placing the different TSPCK episodes into categories of increasing sophistication and turning their description into the criteria for each category.

4.4 Analysis of the identified TSPCK episodes

The purpose of the observations in this chapter was purely to capture the TSPCK episodes as they occurred in the lesson as much as possible. The number of TSPCK episodes identified in the lessons shown in Table 4.2 to provide an overview of each of the lessons taught by each of the teachers. The various TSPCK episodes were logged by enumerating the number of individual TSPCK components and determining the extent to which they work together in the explanation of a concept. The agreement was done between the researcher, a science education expert and the supervisor.

Table 4.2: Overview of TSPCK episodes in lessons of two teachers in the pilot study.

Teacher	Lesson	TSPCK episodes in each lesson	Total number of episodes in 2 lessons
Liso	1	**5**	**9**
	2	**4**	
Qondi	1	**4**	**10**
	2	**6**	

Table 4.2 indicates that the teachers demonstrated almost equal total numbers of TSPCK episodes. First, the TSPCK episodes were grouped according to the numbers of components found to be interacting. Secondly, those that did not fit perfectly into the quantity categorization were grouped together for analysis that is more detailed. For example, these were TSPCK episodes, which while having a certain fixed number of TSPCK components, had an additional character visible such as a repeating component. For each teacher, the identified TSPCK episodes could be categorized into three distinct categories that are differentiated by the level of sophistication demonstrated by the TSPCK episodes. Table 4.3 shows the different types of TSPCK episodes that were observed and analyzed in the video recorded lessons. The nature of these episodes became the criteria used to develop different categories and classifications of these episodes using the rubric.

Table 4.3: The nature of TSPCK episodes observed from the classroom practices of experienced teachers

	Type 1 :	**Type 2:**	**Type 3:**
	• These are simple 2- component TSPCK episodes**.** • The two components interacting are clearly, explicitly distinguishable • Both components work together to support an explanation of a single or pair of concepts that are related	• These are 3- component TSPCK episodes. • The three components interacting are clearly, explicitly distinguishable • The three components work together to support an explanation of a concept • that is implied and not explicit in the episode	• These are 4- component TSPCK episodes. • The four components interacting are clearly, explicitly distinguishable • Both components work together to support an explanation of a concept
Lisa	5	3	1
Qondi	5	2	3

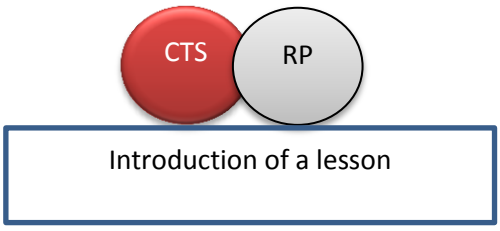
Table 4.3 indicates that the identified TSPCK episodes could be placed into three categories. The first category (type 1) of TSPCK episodes was the simplest and the third category (type 3) is the most sophisticated. Table 4.3 further shows that the two teachers also had equal numbers of category 1 TSPCK episodes and slightly differed in the numbers of type 2 and type 3 episodes. The purpose of this activity was not necessarily to compare the two teachers but to capture the kinds of TSPCK episodes they display in their classroom teaching. Similarities and differences are also noted in both teachers' lessons. In the discussion below, I identify and select representative examples of each type of TSPCK episodes listed in Table 4.3 in detail for the two teachers. This means that I have drawn an example of a type 1, 2 and 3 episode for teacher Liso first, the same is also done for teacher Qondi. Examples from video transcriptions that show what is actually happening and what the teacher is saying at the time of concluding that an episode of TSPCK has been identified are discussed with the TSPCK maps in the sections that follow.

4.4.1 TSPCK episodes in Liso's teaching

Teacher Liso taught lessons on the topic 'chemical energy and change.' The first lesson was largely an introductory lesson on the topic where the teacher recapped the previous grade content knowledge. The

key concepts discussed in this lesson were to distinguish exothermic and endothermic chemical reactions. In the second lesson, the emphasis was on chemical change in the context of acid-base reactions. Teacher Liso displayed two types of TSPCK; type 1 and type 2 episodes. There was no type 3 TSPCK episodes displayed in his first lesson and only one is noted in the second lesson. Tables 4.4 – 4.9 show examples of types 1 – 3 TSPCK episodes observed in each of the two teachers' lessons. A diagrammatic description of how each of the different types of TSPCK episodes looked like is also shown in the form of a TSPCK map as described in section 4.2. A discussion of the evidence pointing to the existence of distinguishable TSPCK components that interact in teaching segments is shown in the tables below.

Table 4.4: An example of a two component TSPCK Episode

What is happening (Time 3min into lesson 1)	**Transcribed teaching segment**
The teacher introduced the lesson by recapping what the class had learnt in Grade 10. The teacher went ahead to ask learners to explain what they understood by the terms *exothermic and endothermic reactions.* The teacher used a table drawn on the whiteboard to compare (CTS) exothermic and endothermic reactions.	**1.47** **Teacher Liso: "**…a lot of work that comes from grade 10…I just want to quickly touch on a few things …can you please explain to us what is an exothermic reaction? *Learner 1 answers by saying it is a reaction that 'output's' heat* "…that last word that you use…?" **Learners** whispering "*releases"* **Teacher Liso:** "Releases what…? Is it just heat…ok, releases energy, and one of the forms of energy released is heat and the other form of energy could be sound…an explosion, a very large bang…(RP)...that's an exothermic reaction releasing energy in the form of sound, now what is an endothermic reaction?" **Teacher Liso:** "Let's summarize the similarities and differences between the two concepts."
TSPCK MAP  CTS=Conceptual Teaching Strategies RP=Representations and analogies	

Discussion

At face value the discussion on the meaning of *endothermic and exothermic* seemed like the teacher recalling student knowledge. However, the teacher moved to place a table to compare exothermic and exothermic reactions (CTS**)** carrying on with the effort to establish the meaning of the two terms by referring to the table. This indication shows that the terms are introduced and meanings established, these meanings are important or needed in the understanding the concept of *exothermic and endothermic* reactions. It should be noted that the teacher uses the following strategies:

- Repeats the words endothermic and exothermic for emphasis
- Summarizes the concepts under discussion using a table, it is now time for a comparison.

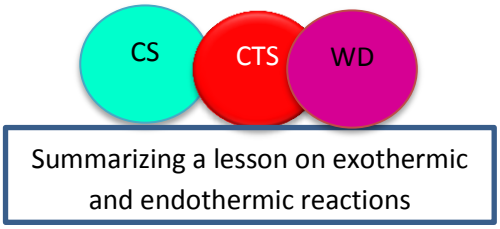
The teacher uses chemical equations in a symbolic representation to explain the concept of breaking and formation of bonds and goes on to use submicroscopic representations (including electrons) and macroscopic analogy to go deeper into explaining '*absorption of energy for bond breaking.'* He further explains that the breaking of bonds requires energy while the formation of new chemical bonds release energy, the teacher uses some aspects of variation theory (Nilsson, 2014) by simultaneously discussing bond breaking, bond formation, energy absorption, energy release, endo and exothermic reactions and the overall heat of the reaction in the same teaching segment.

Therefore, the teacher uses symbolic representations to explain the concept.

Microscopic, submicroscopic and Macroscopic as well as an analogy of separating magnets to go deeper into explaining the absorption of energy for bond breaking in the same way that there is a need to use energy in separating two magnets that are held together by a magnetic force.

Table 4.5 is an example of a type 2 TSPCK episode characterized by 3 components which work together to support the explanation of a concept in teacher Liso's same lesson on thermodynamics. The lesson is still on thermodynamics but this segment further engages the learners with what is difficult (WD) to teach in the topic, which is the explanation of an exothermic reaction as giving away energy from the reacting substances, however, the same energy that is given away is gained by the environment. The concept of the exothermic reaction is directly opposite that which occurs during an endothermic reaction. The flow of energy is not tangible and difficult for learners considering that in the end no energy is lost or gained in a total isolated system.

Table 4.5: An example of a three component TSPCK episode

What is happening	**Transcribed teaching segment**
The teacher draws a table on the white board where he compares similarities and differences between endothermic and exothermic reactions(CTS), as key concepts to be understood (CS). The teacher then goes on to explain energy going into the system and out of the system. The teacher then explains that energy may be treated either as a reactant or a product during a chemical reaction. The decrease in temperature while there is absorption of temperature is a difficult concept (WD) for learners to understand.	**Teacher Liso**"…you need to be very careful with the concept of 'endo' which means decrease in temperature (referring to the comparison table (CTS) on the whiteboard because of it absorbing energy, we tend to think its keeping more energy in the substance but the point is that energy is coming from the environment, something else is becoming colder."(WD). **Teacher Liso:** "When you understand this you understand 60% of chemical change." (CS)
TSPCK Map	

*CS=Curricular Saliency *CTS=Conceptual Teaching Strategies *WD= What is difficult to teach

Discussion

The teacher began the lesson by distinguishing between endothermic and exothermic reactions, explaining the meaning of each term in a way that extended the understanding of the learners beyond merely defining the two terms but relating them to the law of conservation of energy (CS). The teacher constantly contrasted the two concepts, by explaining the other in contrast to the other through distinguishing between the aspects of energy changes that take place in each of the processes through comparison. This is a form of a conceptual teaching strategy (CTS) that uses variation theory as it focuses on contrasting two concepts that are in contrast to each other. The concepts are varied when the teacher says, for instance, that in an endothermic reaction energy is absorbed into the chemical system and asks the learners what happens to the energy in an exothermic reaction. Similarly, learners can also determine *delta H (*ΔH*)* of a reaction which can either be positive or negative, depending on whether the reaction is an endothermic or an exothermic reaction. However, in the same segment, the teacher made note of the fact that 'endo' means that the energy of the reactants increases as a result of loss of energy from the environment. This showed the incorporation of what is difficult (WD) about distinguishing

exothermic and endothermic reactions because the loss of energy from one system (the environment) means that energy is gained by the other system (the reacting chemicals) in the case of chemical reactions.

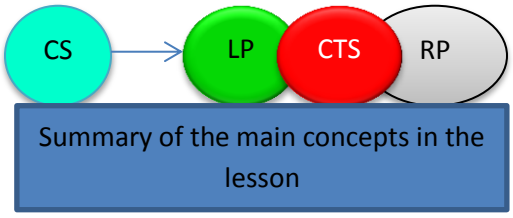
There was only one 4 component TSPCK episode in teacher Liso's lessons. Table 4.6 describes how the components in this segment interact to form a type 3 TSPCK episode.

Table 4.6: An example of a four component TSPCK Episode

Min 4:50: What is happening	**Transcribed teaching segment**
Teacher distinguishes between endothermic and exothermic reactions in terms of bond breaking and bond formation respectively (CS). Draws an arrow in between reactants and products for the word equation for the chemical reaction between Hydrogen and Oxygen to form water. Writes the chemical equation on the whiteboard using chemical symbols (LPK). Draws Lewis structures of water H_2O; H_2 and O_2 on the whiteboard, showing all the electrons (RP) …as he writes the products on the board (RP).	**Teacher Liso:** "Chemical reactions are about the making and breaking of bonds, ok, that's what it's all about." "If I look at the reaction of …hydrolysis of water to form Hydrogen gas and Oxygen..." "…the electrolysis of water, that's a chemical reaction taking place, I am breaking bonds and I am making bonds, I am breaking bonds between Hydrogen and Oxygen and I am making bonds between my Hydrogens and I am making bonds between my Oxygen." "…at the end of term 1 we did this…" "…remember that, Ok, from that we can see that there is a bond between my Oxygen and my Hydrogen (LPK), so if I want this reaction to take place, I am going to have to break these bonds "…so I need to separate Oxygen and Hydrogen…then the reaction takes place, I am then going to form Hydrogen and I am going to form Oxygen…Ok, so you can see that I am taking stuff out I need to break bonds and when I am taking stuff together, its making new bonds..." "…But now if I want to break bonds…is that molecule going to draw energy or release energy to break bonds?" **Learner:** *' ...Release… '* *[Teacher rephrases the question for clarity]* "…If I am breaking bonds, am I putting in energy…to break because I need to physically…those things are held together by electrostatic forces because they are sharing electrons, so if I want to separate them from...

What is happening	Transcribed teaching segment
Demonstrates by separating his hands (RP). The teacher completes a table on the chalkboard that shows differences between endothermic and exothermic reactions (CTS).	"...each other I need to put in energy, so when I am breaking bonds that molecule is going to.....absorb and it's going to absorb more energy to break the *other* Hydrogen-Oxygen bond…energy needs to go in to separate them… think about … taking two magnets apart… you need to put energy to get those magnets separate…(RP). Ok, so if my new bonds are formed, what's going to happen there? **Learners**: *'it is releasing energy.'* **Teacher Liso:** "…we can see that in all chemical reactions I've got absorption to break up bonds and I've got release of energy to form new bonds, any questions up to that point because this is critical…"

TSPCK Map



*CS=Curricular Saliency LP=Learner Prior Knowledge CTS=Conceptual Teaching Strategies RP=Repre-sentations

Discussion

The teacher emphasized in this summary the big ideas in this topic which are the absorption of energy during bond breaking and the release of energy during bond formation (CS). He went on to state that energy can either be perceived as a reactant or a product in all chemical reactions. In reminding the learners about Lewis' diagrams covered in the first term, the teacher attempted to link Learner Prior Knowledge (LPK) to the concept being discussed. The teacher employed Representations (RP) in the form of symbolic chemical equations and microscopic Lewis diagrams of H_2O, H_2 and O_2 that show chemical bonds and electrons that bind them together in an electrostatic force, the strategy (CTS) the teacher employs brings together the concept of endothermic and exothermic reactions.

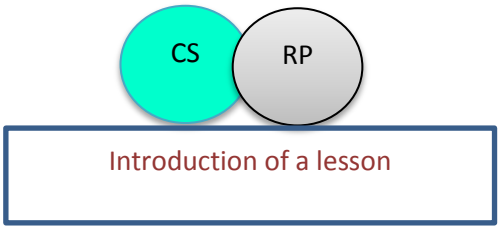
The TSPCK episodes shown above represent examples of each type of TSPCK episodes observed in the teaching practice of teacher Liso. As mentioned earlier, the purpose of identifying these episodes was mainly to capture different categories of TSPCK that can be seen in classroom lessons of practicing teachers. In the section that follows, a similar presentation on TSPCK episodes identified from teacher Qondi's lessons is made.

4.4.2 TSPCK episodes in the teaching of teacher Qondi

Qondi taught the topic electromagnetism. The first lesson was largely an introductory lesson on the topic potential energy and the second lesson was on electromagnetism. Qondi had all three types of TSPCK episodes including type 3, which shows the most sophisticated TSPCK episode. I discuss, in the sections that follow, examples of his TSPCK episodes; I focus on those that show slight differences to those of teacher Liso.

Nine (9) TSPCK episodes were identified in Qondi's two lessons, I have purposefully selected from each of his lessons examples that explicitly show 2, 3 and 4 components that interact in a teaching segment. The following tables show these components and they are discussed in a similar way to how Liso's lessons have been analyzed. I begin with an example of a two component interaction.

Table 4.7: Another example of a two component TSPCK episode

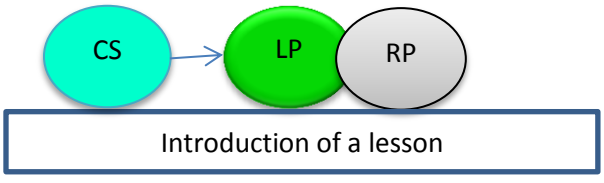
What is happening (2.07minutes into lesson 1)	**Transcribed teaching segment**
Teacher begins the lesson with a brief review of the knowledge held by learners on magnetism. He asks learners to recall that magnets have a North Pole and a South pole, and that the red and blue colors represent these poles respectively. {*The teacher lifts a bar magnet and explains the meaning of the blue and red colours (RP) and the cause of the polarity in terms of the domains of the ferromagnetic materials}*	**Teacher Qondi:** "The term electromagnetism basically deals with electricity and magnetism...which is going to be our primary focus for this lesson… (CS); now let us just review our current knowledge of magnetism. If you look at this right, there are certain points that you need to look at…"
TSPCK Map  *CS = Curricular Saliency *RP = Representations	

Discussion

In this segment, I identified a TSPCK episode with 2 components. The first is shown by emphasis on describing the domains of ferromagnetic materials as causing magnetic properties of materials, which is an element of curricular saliency (CS). The teacher moved on to explain that an electric current carrying wire also has a magnetic field that orients itself in a particular direction. Pointing at the bar magnetic is used to demonstrate the actual point of discussion, a macroscopic representation (RP); the teacher explained that the domains of the magnet are caused by moving electrons within the ferromagnetic materials.

Table 4.8 presents a 3 component TSPCK episode from teacher Qondi's lesson on mechanical energy.

Table 4.8: An example of a three component TSPCK Episode

What is happening (lesson 1)	**Transcribed teaching segment**
(00:51) The teacher begins the lesson by defining mechanical energy as all forms of energy (CS) including potential energy, kinetic energy conservation of chemical energy. He then uses visual slide representations to show learners different forms of energy, and asks learners not to write anything, but only definitions. The teacher then probes learners' prior knowledge on forms of energy. (LPK). He goes on to probe learners' prior knowledge on the topic of discussion. **6:13 Mins** The teacher probes learners' prior knowledge about potential Energy. The teacher then moves on to discuss potential energy (PE) by first asking learners what they understand by potential energy from their previous grades. (LPK)	**Teacher Qondi:** "Can I hear from you, is there any familiar word in that topic. Energy, if you remember what energy is who wants to remind us..." (LPK). "…there are all sorts of energies, including mechanical energy, radiation energy, where there is no medium involved"(CS) *"*...who has read or heard about Potential Energy."*[A student answers by saying energy is the ability to do work, to which the teacher says is a general definition of energy and goes on to define potential energy.]* **Teacher Qondi:** "…this is energy of an object related to its position. It's the kind of energy from a relationship between two more objects. There is PE between the stars, the sun... have PE between each other, which is caused by gravity. There is PE between you two [*pointing at two students*], because of the distance in between..." (RP).
TSPCK MAP  *CS=Curricular Saliency LP=Learner Prior Knowledge RP=Representations	

Discussion

The teacher begins the lesson by defining the key pre-concepts needed prior to teaching, and probed learners' familiarity with the new terms. He then moved on to introduce the topic for discussion, which is potential energy (PE). He again probed learner prior knowledge, before defining what potential energy means, which is the 'big idea'. The establishment of the meaning of potential energy would contribute towards understanding one of the big ideas in energy: potential energy. The teacher provided explanations on key aspects of potential energy that should be understood, for example *"kind of energy from a relationship between two or more objects*", this was an indication of curricular saliency (CS) in the topic. He further used examples that were at a sub-macroscopic level and using a magnet, which is familiar to learners as a macroscopic representation (RP). On overall, the teacher demonstrated drawing on the components Learner Prior Knowledge (LP); Curricular Saliency (CS) and Representations and analogies (RP). The slide showing the magnet and magnetic field lines is a submicroscopic representation that bridges understanding that magnets have domains that move from the North to South Pole of the magnet. The teacher uses examples and visual slide projections to explain and differentiate between potential energy and other forms of energy.

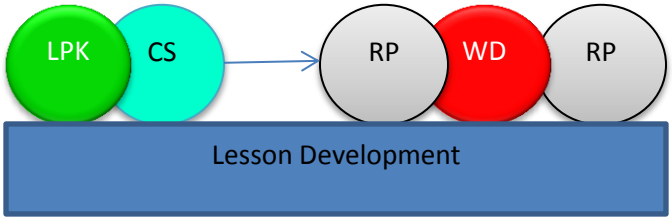
Using another lesson from teacher Qondi, a TSPCK episode which is considered to be a type-3 episode has more than 3 components evident in the lesson video. The teacher is still teaching the topic on electromagnetism. It is evident in the table that within the three components that are identified, one component (RP) was repeated in this segment. A description of what happened in the lesson, verbatim transcriptions of actual teacher talk, the TSPCK map and a discussion of how the identified components were agreed upon is shown in Table 4.9 as an example of a four-component TSPCK episode.

Table 4.9: An example of a four component TSPCK episode

What is happening (Time **4:07Min** into lesson 2)	**Transcribed teaching segment**
The teacher reinforces a learner's response with a positive comment, and expands on what one of the learners has said;	**Teacher Qondi:** "…what makes this particular material special? What makes ferromagnetic material like nickel, cobalt, iron etc. special...? (LPK). [*Teacher showing a bar magnet to the learners.]... such* that they can be magnetized making us able to detect magnetic properties around them? He repeats the question again, rephrasing it to make it clearer. What makes iron special? What is it about iron that makes it able to manifest magnetic properties (CS) around it?" [*The teacher repeats this statement three times x3]* **Learner:** '*…the direction of the electrons'*

What is happening	Transcribed teaching segment
Then the teacher gives a short exercise to test learners' understanding so far.	**Teacher Qondi:** "...there are moving charges within the domains of that particular magnetic material. Moving electrons which tend to create a magnetic field in the same direction within the domains…" (CS) *repeats x2* "...and therefore these little magnetic fields within each domain of the ferromagnetic material move in the same direction (CS) and they add to each other to create a magnetic field, that is what makes ferromagnetic materials to be so special". [*The teacher repeats this statement three times again x3]*
The teacher calls on two learners to come forward and perform the demonstration as he guides them. He gives both learners a bar magnet and compass (RP) and asks the two demonstrating learners to face the rest of the class and take the compass and place it close to the bar magnet and tell the class what happens. He then asks them to rotate the compass in the one position as the two learners make observations on what happens to the compass needle. The two learners observe that the needle remains in the same position, as the compass is rotated (WD). The teacher then goes on to consolidate the explanation, using visual slide illustration showing a representation of the compass and the bar magnet, with the magnetic field around a magnet and the constant position of the compass needle (WD) as the compass is rotated around the bar magnet.	I want you to draw a bar magnet in your books and indicate for me the direction of the magnetic field around a bar magnet. You can put the North Pole on the left or right (RP) use a pencil and a ruler [*teacher walks around the class observing what learners are doing, explaining what he expects]*. **Min: 09:38** "Now I want to demonstrate the direction of the magnetic field using a compass and a bar magnet" (RP). **(10:25 Mins)** 'Okay what important aspect of magnetic field lines around a bar magnet do you remember (LPK) x 2? Students respond correctly. "Very well they never cross and they do not touch. In which direction do they move? (WD). ...From North to South Pole, the teacher repeats and confirms learners' responses. So roughly, each of you should be having something like this" *He then draws a diagrammatic illustrations of a bar magnet indicating the North Pole and South Pole and the direction of the magnet field lines.*

TSPCK MAP



*LP=Learner Prior Knowledge CS=Curricular Saliency RP=Representations WD=What is Difficult

Discussion

At the beginning of this segment the teacher probes learners' prior knowledge (LPK) in the topic by asking them what makes ferromagnetic materials special before he goes on to define the big idea. Big ideas fall under curricular saliency (CS). He then gave a short formative assessment exercise for learners to do in their classwork books. He used the short test for testing learner understanding. He then called on two learners to come forward and carry out a demonstration using bar magnets and a pair of campus. He then consolidated his explanation using visual depictions, to enhance clarity on the concept of the magnetic field, to explain the concept that appears difficult to comprehend (WD).

The TSPCK map for this episode, which shows a number of interactions of the components, forms the episode with the highest number of interacting components in all the lessons observed for both Liso and Qondi. These components interact with each other in this episode in a way that I have represented in the TSPCK map shown on Table 4.9 that includes the nature of these interactions. The component LPK interacts with CS and I notice also the repeated use of Representations (RP) in the form of diagrammatic representations on the whiteboard (symbolic), real magnets (macroscopic) brought into class, and the representation of electron movement in ferromagnetic materials (microscopic) that cause magnetic fields around the magnet to emphasize the concepts that make the topic difficult (WD) to understand.

The Number of TSPCK episodes evident in the video-recorded lessons of the two science teachers in topics other than stoichiometry is summarized on Table 4.3 at the beginning of this chapter. The table also shows the nature of the episodes, how they emerged, and the latent features observed as emergent from the analysis of the episodes and their components. The purpose of this study is to see how the development of TSPCK among teachers manifests itself in their classroom practices. Table 4.4 and the pre-ceding tables also include brief overviews of the lessons to offer readers a context in which the lessons were taught as well as a review of the content in each of the lessons. Through content analysis, the emerging and salient features of teachers' verbatim speech are obtained. The study took note of the way that these episodes emerged in the classroom for development of criteria for categorizing different types of TSPCK episodes.

The development of a rubric in this chapter is premised on the need to grade the quality of TSPCK episodes observed in real classroom practice. The developed rubric will be used as a guide to analyze TSPCK in the teaching practices of the participating practicing teachers. Based on the types of TSPCK episodes identified above, the rubric in the following section has emerged.

4.5 The emerging TSPCK rubric with some examples

In the discussion above, I illustrated examples of how the different kinds of TSPCK episodes were captured in the teaching of the two practicing teachers. The table below shows the emerging rubric that contains criteria considered for each type of category. I use words to describe the level of sophistication observed in a TSPCK episode such as 'Basic' for the interaction of just two components in a segment as shown in Table 4.10. I have also included some examples of extracts that I have not used in the discussions of the lessons. The examples serve to show users of the rubric samples of teacher segments that are considered to be episodes in each of the categories or types of TSPCK for ease of marking.

Table 4.10: Developed rubric for the analysis of enacted TSPCK components

Type 1: Basic Episodes	**Type 2: Moderate Episodes**	**Type 3: Proficient Episodes**
• These are simple 2- component TSPCK Episodes**.**	• These are 3- component TSPCK episodes.	• These are 4- component TSPCK episodes interacting clearly and explicitly distinguishable. with one of the components repeated in the teaching segment
• The two components interacting are clearly, explicitly distinguishable	• The three components interacting are clearly, explicitly distinguishable	• The three components interact clearly, explicitly and are distinguishable, the repeated component is also distinguishable
• Both components work together to support an explanation of a single or a pair of concepts that are related	• The three components work together to support an explanation of a single concept	• The four components interacting are clearly, explicitly distinguishable

4.6 Concluding remarks

The study gained insights into the development of TSPCK and descriptive information about a data set through content analysis (Fraenkel, Wallen and Hyun, 2012). The existence of a single TSPCK component does not sum up to a developing nor developed TSPCK, there has to be two or more components interacting to form a TSPCK episode. This means that the mere existence of a TSPCK component in the data does not show improving TSPCK. Content analysis helped the researcher in identifying all possible interactions of TSPCK components that existed in the data. The purpose of

piloting the rubric using the lessons taught by teachers who did not participate in the lesson study served an important purpose of providing the study with a tool that is based on real data that I could use to analyze and make conclusions about the quality of enacted TSPCK to be observed in my sample.

It is noted that the various types of interactions could not be easily deciphered from the data because many times the level of sophistication of the interactions was not always apparent as analysis has shown that there are so many ways in which these interactions occurred, even when the teachers had a single objective in the teaching of a particular aspect of the curriculum. The various manifestations of TSPCK episodes and component interactions have led to the development of a specific rubric in this chapter. The rubric has also taken into consideration that there can be subcomponents within a single TSPCK component, such as the curricular saliency (CS) or the different levels of representations in the component Representation and analogies (RP). Furthermore, other components may be repeated in a single teaching segment. Having gone through this exercise, I am convinced of the need for a different rubric to measure the quality of TSPCK observed in action. While the development of this rubric was not my target, however, it was a needed additional step. I have graded the observed TSPCK episodes into *Basic; moderate or Proficient episode* categories, as shown in Table 4.10. The next chapter, Chapter 5 presents the findings of the data obtained in this study, where the newly developed rubric is used.

CHAPTER FIVE

5. Findings

5.1 Introduction

The previous chapter focused on the development of a rubric to guide analysis of the data discussed in this chapter. In this Chapter, data collected in the study is analyzed in a composite way that considers qualitative aspects of content analysis of verbatim speech and participant actions as discussed in Chapter 3. I begin by giving a brief summary of the way data has been collected and organized in preparation for analysis. The organized data is then analyzed in two categories; data establishing effect of the intervention on the quality of planned TSPCK as well as for impact on classroom teaching which reflects TSPCK enactment. This Chapter closes with a summary of major findings from this study.

5.2 A brief account of data collection

This study aimed at examining the impact of a lesson study on the quality of TSPCK in stoichiometry of practicing teachers. The research questions asked in the study are: (i) how does a lesson study influence the development of TSPCK amongst practicing teachers? In addition, (ii) how does the developed TSPCK translate to their classroom practices? It is important to recall that a lesson study is a form of intervention in which participating teachers are exposed to mentoring in a specific topic through iterative planning meetings, teaching a particular topic, and meeting again to discuss ways of delivering an improved lesson. In the present study, as mentioned in Chapter 3, the cycles of meetings were considered as an intervention that spread over a period of four weeks, with 2 hour meetings held during each week as described in the section 3.6 on 'Treatment' in chapter 3 (page 14). The cycle of meetings was repeated until all three participating teachers had taught a lesson on the mole following a lesson plan designed in a meeting prior to each lesson. The teachers taught the developed lesson on consecutive Saturdays during the intervention. The 'mole' is a concept of stoichiometry that is taught to Grade 11 learners by the three participating teachers in their respective schools. This meant that the teachers taught the lesson on the mole at different stages of the intervention.

Two sets of data were collected following the intervention. The first set of data is meant to address the question on the influence of the intervention on the quality of TSPCK in stoichiometry and in establishing insights into the influence, if any, of the intervention on topic specific PCK. Data is collected using a validated TSPCK tool in stoichiometry; this developed tool is then administered as a set of pre- and Post- intervention TSPCK tests. The analysis of shifts in the quality of TSPCK between these tests provided an overview of the impact of the

intervention, a response to the first research question. Supplementary data to answering the first question were verbatim transcriptions of the recorded content discussions during each of the lesson study meetings as they progressed. This data shed light into emerging signals of developing TSPCK as the lesson study progressed, thus providing a response to the 'how' part or aspect of the first question, that is on how the influence of the intervention emerged.
The second sets of data were to assist with answering the second research question that asked for evidence of the influence of the intervention on classroom practice. Data collected were in the form of video-recorded classroom lessons of each of the three participating teachers, teaching a lesson on the mole with Grade 11 learners in their respective schools (see details on school backgrounds and demographics in Chapter 3). The analysis was interesting as the three teachers delivered the lessons at different stages of the intervention. A brief account of the analysis of the different data is given in the section below.

5.3 A brief account of data analysis

(i) Analysis for impact on the quality of TSPCK

As mentioned in Chapter 3, the practicing teachers completed pre- and post-TSPCK tools that were analyzed using a rubric of planned TSPCK (Mavhunga and Rollnick 2013); the full rubric is shown in Appendix II (page 95). The rubric is criterion based showing differing degrees of quality for each of the TSPCK components across 4 categories ranked from 1 to 4. A TSPCK score of one (1) shows a 'Limited' quality of TSPCK, which is the lowest on the scale. The next category shows TSPCK considered to be 'Basic' with a score of two (2), followed by a 'Developing' quality of TSPCK with a score of three (3) and the highest score of four (4) is assigned to an 'Exemplary' quality of TSPCK. Figure 5.1 presents an extract of the rubric for espoused TSPCK, where according to Park and Olivier (2008) espoused TSPCK refers to PCK demonstrated in a planning context.

TSPCK Components	Limited(1)	(2) Basic	(3) Developing	Exemplary (4)
Learner Prior Knowledge including misconceptions	• No identification/No acknowledgement/ No consideration of student prior knowledge or misconceptions • Repeats standard definition with reference to any other component of TSPCK	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Repeats standard definition drawing on one other component of TSPCK	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Expands and re-phrase explanation using two 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 three or more other component of TSPCK interactively

Figure 5.1: An extract of the rubric for TSPCK in a planning context – Espoused TSPCK

I scored the practicing teachers' responses in the completed TSPCK tools with one other rater who is familiar with the structure of the TSPCK tools and the rubric. The scoring was first done independently, and then the scores from the two independent raters were compared and then discussed. I acknowledge that scoring my own tools would present problems that are linked to bias; therefore, I had to make use of two other independent co-raters. An inter-rater reliability of 80% is obtained as there is an average of 16 out of 20 agreements in the scores for the three teachers. There is a high concordance or degree of agreement among raters. Each point of difference was discussed until an agreement was reached. In the event that no agreement is reached, a third opinion for each of the TSPCK scores is further obtained from a science education researcher who is also familiar with the rubric to avoid inconsistency and personal destructions (since I also had to rate myself). In this way, the researcher minimizes misinterpretation and the bias that may result from being tired of doing repetitive tasks. The scores generated from the analysis are given in Table 5.1. The table's first column represents the pseudonyms of the three participant teachers. Columns 2 to 6 are the individual TSPCK components with the last column representing average scores for the pre- and Post-tests for each participant.

Table 5.1: Pre- and Post-TSPCK scores of the three practicing teachers

Practicing Teachers	Learner Prior Knowledge (LPK)		Curricular saliency (CSA)		What is difficult to teach (WDT)		Representations (REP)		Conceptual teaching strategies (CTS)		Averages	
	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post	Pre-	Post-	Pre-	Post-
Andy	4	4	3	3	3	4	2	3	3	3	3	3
Alex	4	4	2	3	2	4	2	2	2	2	2	3
Gigi	4	4	2	3	2	3	2	4	2	3	2	3
Average	**4**	**4**	**2**	**3**	**2**	**4**	**2**	**3**	**2**	**3**	**2**	**3**
Group average pre-test TSPCK score								**2**				
Group average Post-test TSPCK score								**3**				

The last row reflects the group average scores for the three participants. In this analysis, to calculate a participants' overall TSPCK score, as well as the group's overall TSPCK score which is obtained by applying the mathematical averaging function. At face value, this function may appear as mere summing up of the scores of the components and representing the average. This is not so as literature points out that PCK and by association TSPCK, is not the sum of the individual components but their influence on each other (Abell, 2008). When one looks closer, it is noticed that the criteria used in the TSPCK rubric call for both knowledge of each TSPCK component and for its interaction with other components, note the shaded text in Figure 5.2. Thus, the use of an average for the group serves as a proxy of all the individual scores that has taken component interaction at the individual level into account. The statements that are shaded in Figure 5.2 show that 'Basic' TSPCK involves the component in the first column having to draw on one 'other' component of TSPCK. This shows that for a participant to get a score of two (2), there has to be evidence that what they say or define draws on two TSPCK components. Similarly, the interactive use of two (2) other components warrant a score of three (3) that signifies a 'Developing' TSPCK, whilst an 'Exemplary' TSPCK with a score of four (4) interactively draws on three other components to confront misconceptions and confirm accurate understanding. The shaded regions in the table show how TSPCK episodes interact increasingly in the criteria, analyzed through the subjective assessments of independent raters.

TSPCK Components	Limited(1)	(2) Basic	(3) Developing	Exemplary (4)
Learner Prior Knowledge including misconceptions	• No identification/No acknowledgement/No consideration of student prior knowledge or misconceptions • Repeats standard definition with reference to any other component of TSPCK	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Repeats standard definition drawing on one other component of TSPCK	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Expands and re-phrase explanation using two 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 three or more other component of TSPCK interactively

Figure 5.2: An extract of the espoused TSPCK rubric showing component interactions

Therefore, the average group scores were calculated as a measure of their possible effect onto each other. With regards to that, Abell (2008) argues PCK is not the sum of the individual components, rather their interactions, likewise I do not consider TSPCK to be the sum of the mere components but their interactions as also alluded in Aydin et al. (2015). Thus, considering the overall group score for the pre-test (that is, 2) which can be seen to be lower that the Post-test (which is, 3), the practicing teachers seemed to have experienced improvement in their understanding of the knowledge components and their interactive nature. The findings from the

TSPCK tools are discussed in the sections that follow, supplemented with the analysis of the recorded data from the lesson study meetings.

(ii) Analysis for evidence of TSPCK in classroom settings

For establishing the influence of the lesson study intervention on classroom teaching of the participating teachers, the recorded classroom lessons were analyzed for the presence of TSPCK episodes using the rubric of enacted TSPCK developed in Chapter 4. The rubric was used to analyze for TSPCK episodes as they emerge in classroom settings. It is different from the rubric shown in Figure 5.1 in a sense that evidence of TSPCK is seen in action, rather than in predetermined tasks as in the TSPCK tool for espoused TSPCK. In the TSPCK tool, participants are consciously aware that they are responding to predesigned tools and the sequence of engagement with components may be controlled. The analysis for TSPCK episodes in video-recorded lessons was similar to that done in Chapter 4, where TSPCK episodes were first identified, described in detail together with the components present and their interactions represented through TSPCK maps. Similarly, here, a TSPCK episode is a teaching segment that consists of at least two components interacting to supports a single or a pair of concepts that are related.

5.4 Findings

The findings from the analysis of the data mentioned above show two salient features about the impact of the lesson study as an approach for use in developing the TSPCK of practicing teachers in stoichiometry. These are: (i) the exposure of practicing teachers to a lesson study showed an improvement in the quality of reasoning and planning which is the planned TSPCK for teaching stoichiometry. Close analysis of the scores of the individual TSPCK Components indicate an observable positive improvement in two specific components; (ii) The improvement in planned TSPCK in the topic manifests in classroom practices of the three participating practicing teachers and generally spreads across the three categories with 2, *3 and 4* component TSPCK episodes which demonstrated *basic, moderate and exemplary* enacted TSPCK that were observed in the lessons as the intervention progressed. Details of these findings are discussed in detail in the section that follows.

5.5 Impact of the lesson study

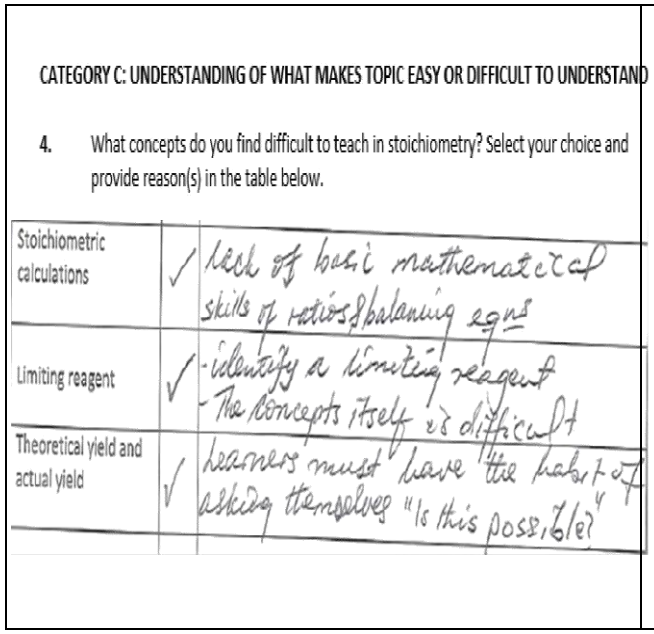
5.5.1 Positive shift in the quality of espoused TSPCK in stoichiometry

The major finding about the overall impact of the lesson study intervention is that there was an improvement in the quality of TSPCK in stoichiometry of the practicing teachers during the intervention. The group average scores when compared before and after the intervention show an average increase from 2 to 3 respectively. Mathematically, the average score for the pre-test was 2.3; however, this number is rounded down to 2 (limited) as the rubric has no criteria for fractions. A group post-test score of 3 (developing) indicates that on average, the practicing teachers have improved to a level where there is evidence of considering at least three components of TSPCK and drawing on them interactively when planning to teach about the mole.

A closer look at the teachers' average group scores in Table 5.1 across the individual TSPCK components, indicates a positive shift in the scores across four of the five TSPCK components, with a highest shift seen in the component of *What is difficult to teach* (WD) which shows a jump by two categories from a score 2 to a score 4 for teacher Alex. The analysis indicates that there was no change in the TSPCK scores of the participant practicing teachers for the component Learner Prior Knowledge (LPK), all three showed the teachers starting with a very high score in the Exemplary (4) TSPCK category which did not change after the intervention. While Table 5.1 shows an overview of the scores, it is important to present a qualitative example of responses that demonstrated the positive shifts across components. Figure 5.3 is an extract from the pre- and Post-test responses to a TSPCK tool item that focuses on the component *what is difficult to teach* (WD) for teacher Alex. The handwritten transcriptions may not be clear, I have included a column alongside each of the transcriptions to rewrite and type each of the responses. This response has been chosen to show a 2-category jump as the participant shows a Basic score of two (2) in the pre-test. However, the Post-test score for the same teacher is four (4) that shows an exemplary TSPCK. This is the first form of evidence of TSPCK development. I have selected this example as it shows the biggest 2-category leap in the TSPCK score as a result of the intervention. The actual excerpts from the pre- and Post-tests are shown in the first column of the table whilst the typed out text is shown for clarity in the second column of each table. The test item on the item what is difficult to teach (WD) tests the participant teachers' understanding of what makes the topic difficult to teach or learn. The teachers are given a number of concepts to select from and place a tick into the middle column; the third column in the responses enables the participant teachers to be able to give reasons why they consider the selected concept difficult. Teacher Alex's responses are shown on the next page (Table 5.3).

An example of a 2-category jump in TSPCK scores

Pre-TSPCK response Teacher Alex (Understanding of what makes the topic easy or difficult to understand)



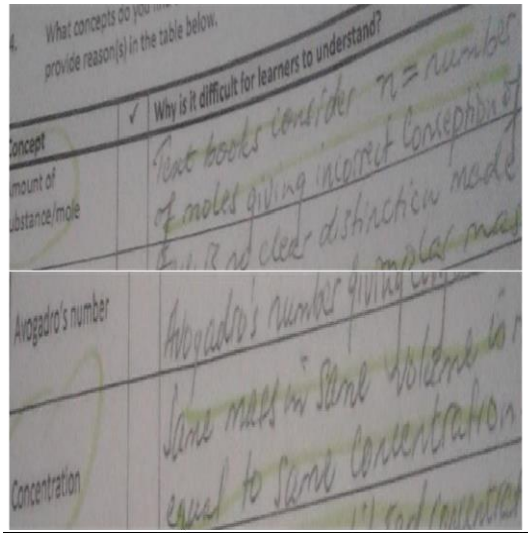
CATEGORY C: UNDERSTANDING OF WHAT MAKES TOPIC EASY OR DIFFICULT TO UNDERSTAND

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

Stoichiometric calculations	✓	lack of basic mathematical skills of ratios & balancing eqns
Limiting reagent	✓	- identify a limiting reagent - The concepts itself is difficult
Theoretical yield and actual yield	✓	learners must have the habit of asking themselves "Is this possible?"

Stoichiometric Calculations	Lack of basic mathematical skills of ratios and balancing equations
Limiting Reagent	Identify a limiting reagent -the concept itself is difficult
Theoretical yield and actual yield	Learners must have the habit of asking themselves 'Is this possible.'

Post---TSPCK response Teacher Alex



✓	Why is it difficult for learners to understand?
Amount of Substance/mole	Text books consider n = number of moles giving incorrect conceptions & no clear distinction made ... molar mass
Avogadro's number	Avogadro's number giving ...
Concentration	Same mass in same volume is not equal to same concentration

Amount of Substance/mole	Textbooks consider $'n = number\ of\ moles'$ giving incorrect conceptions...no clear distinction made...molar mass
Avogadro's number	Avogadro's number giving...
Concentration	Same mass in same volume is not equal to same concentration

Figure 5.3: An extract from teacher Alex's pre-- and Post---test responses to items on the component what is difficult (WD) to teach

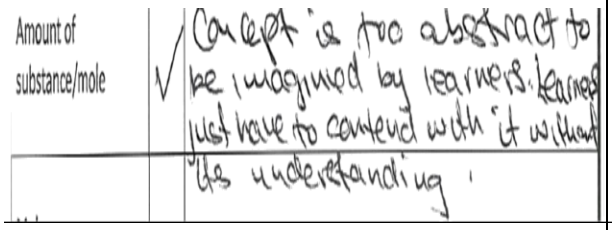
The test item in the extract requires the respondent to indicate what concepts they find difficult to teach in stoichiometry and to provide reasons why they consider the concepts they have listed difficult. Figure 5.3 shows an example of explicit evidence of development of TSPCK for teacher Alex in the component What is difficult (WD) to teach, since a Basic score of two (2) is obtained prior to the lesson study intervention and a Post---test score of 4 (Exemplary) is obtained in the Post---test score. In the pre-test, the teacher only provides algorithmic reasons for finding the concepts difficult by saying that 'learners lack basic mathematical skills of ratios and balancing chemical equations'; 'the concept of limiting reagents is difficult' and ends there; and learners 'must have a habit of asking themselves "is this possible."' In the Post---test, the teacher identifies the concepts that they find difficult to teach in the topic stoichiometry and provides conceptual reasons why they consider those aspects difficult to comprehend for the learners. He explains that the mole is depicted as equal to '*n*' in textbooks rather than the placing of emphasis on the fact that a mole is an amount of chemical substance of which the mol is an SI unit. The teacher also is now able to identify key gate keeping concepts that contribute to learner difficulty in understanding the mole. He explains that concentration is difficult to teach because the same mass of different chemical substances can be diluted in the same volume of solute but the concentrations of the solutions are not the same. The concept of concentration is perceived as difficult with an explanation that uses yet another component: Representations (RP), which is used in the comparison of the dilution of the same masses of different chemical substances.

The second piece of evidence of improvement is the response given to the concept of limiting reagents. After the intervention, the teacher now acknowledges that 'learners do not see the importance of finding amounts to identifying limiting reagents.' Limiting reagents are considered difficult to and a conceptual reason is now given that also points to another component of TSPCK – 'learner misconceptions' (LPK) that learners assume that the reagent with a smaller mass is the limiting reagent or the reagent represented by the smaller ratio of the number of moles is the limiting reagent. Realizing these misconceptions is evidence that teacher Alex is now able to integrate learner misconceptions and prior knowledge (LPK) with what is difficult (WD) to teach. When such concepts are not fully understood, they add to the difficulty of concepts that are regarded as difficult.

An example of a 1-category jump as a result of the lesson study intervention is that of teacher Andy shown in the discussion on the next page. In total, there were six of these one-category jumps in the pre- and Post-test analysis. Figure 5.4 shows evidence of a 1-category leap in the component what is difficult (WD) to teach. The actual except is in the first column of the table as a scanned document. The typed out text is in the right hand side column for clarity. Only part of the handwritten excerpt is shown for the pre-test, the handwriting is so illegible, particularly after the scanning so much that I have only typed out the Post-test response for teacher Andy in this category.

An example of 1-category jump in the component of what is difficult (WD) to teach

Pre-TSPCK test



Amount of substance	Concept is too abstract to be imagined by learners by learners. Learners just have to contend with it without its understanding
Avogadro's number	It's difficult for teachers to even explain its origin and its usefulness. Learners have problems with numbers that have powers (mathematical)...Ions are often ignored as particles...
Limiting reagent	...least amount as in mole ratio in equation or added experimentally is the limiting...

Post-TSPCK test response (typed out text only)

Avogadro's number	Too big a number, difficult for learners to imagine it
Stoichiometric calculations	Underlying concepts may not be obvious for learners, learners follow mathematical procedures without understanding concepts
Limiting reagents	Use masses/volume given to determine

Figure 5.4: An extract from teacher Andy's lesson – an example of a 1-category jump in the component what is difficult (WD) to teach

Teacher Andy's pre-test response only mentions that the concept of the mole is 'too abstract to be imagined by learners and the learners just have to contend with it without understanding.' Reasons for the difficulty are provided and the teacher relates these to learner misconceptions. The teacher goes on to say that he finds Avogadro's constant and its usefulness difficult to explain because 'learners have mathematical problems, particularly with numbers involving exponents and the numbers of ionic particles'. On the limiting reagent, the teacher noted that the misconception as a belief by learners that the 'smaller number in the mole ratios depicted in the

equation shows the limiting reagent'. The teacher has a TSPCK score of 3 in the pre-test because he goes beyond providing broad but valid reasons for the difficulty of the concepts.

In the Post-test, there is an improvement in the way teacher Andy engages with the concepts in that he identifies the concepts with reasons that are related to prior knowledge (LPK) and learner misconceptions. The abstractness of the concept of the mole has been alluded to the fact that the mole is 'both a quantity and a counting unit'; this is what makes it difficult (WD) to teach and to learn. The explanation given for the difficulty in the concept of Molar Volume is explained as being caused by the fact that the learners do not consider that the molar constant 'does not apply to all physical states but only to gases'. Avogadro's' number has been said to be 'too big' for the imagination of the learners. The teacher also identifies the concept of limiting reagents as a key gate-keeping concept and also misconceptions among learners who consider only the masses or volumes of reacting substances in determining the limiting reagents. The reasons given in the Post-test show that TSPCK scores improved from 'Developing' (category 3) to 'Exemplary' (category 4).

For the component of Representations (RP), there is another evidence of a 2-category leap for teacher Gigi that shows TSPCK development from a score of 2 (Basic) to a score of 4 (Exemplary). The evidence from the response of Teacher Gigi is shown in Figure 5.5.

An example of a 2-category jump in the component Representations (RP)

Teacher Gigi obtains a pre-test score of 2 (two) in the component Representations (RP) because the second representation that he likes most does not show all three representations in chemistry but is an algorithmic way of getting equations solved without the explanation of the underlying concepts about reacting substances. The multifaceted representation (Representation 3) chosen by the teacher in the Post-test and his explanations show us that the teachers' TSPCK improves by a two (2) category jump. The extracts of both pre- and Post-test results are shown in Figure 5.5 as evidence of the development of TSPCK. The choice of option 2 in the pre-test show that teacher Gigi only considers algorithmic choices in planning to teach quantitative aspects of chemical change prior to the intervention. Choosing the third representation, which is correct in the Post-test shows that teacher Gigi realizes the need to consider all types of representations used in chemistry to plan for a lesson on stoichiometry and the concept of the mole. These representations range from microscopic representations, submicroscopic representations to macroscopic representations and are associated with conceptual teaching strategies and the pedagogical transformation of content knowledge that enhances the understanding of the topic by learners. The only option showing these three representations is option 3. The test item required the respondent participating practicing teacher to choose, among three representations the one they like to use most in teaching quantitative aspects of chemical change. Because of the clarity of the excerpts in this case, I have not included the typed out text, instead, I have placed the pre-

test response in the left column and the Post---test response in the right column.

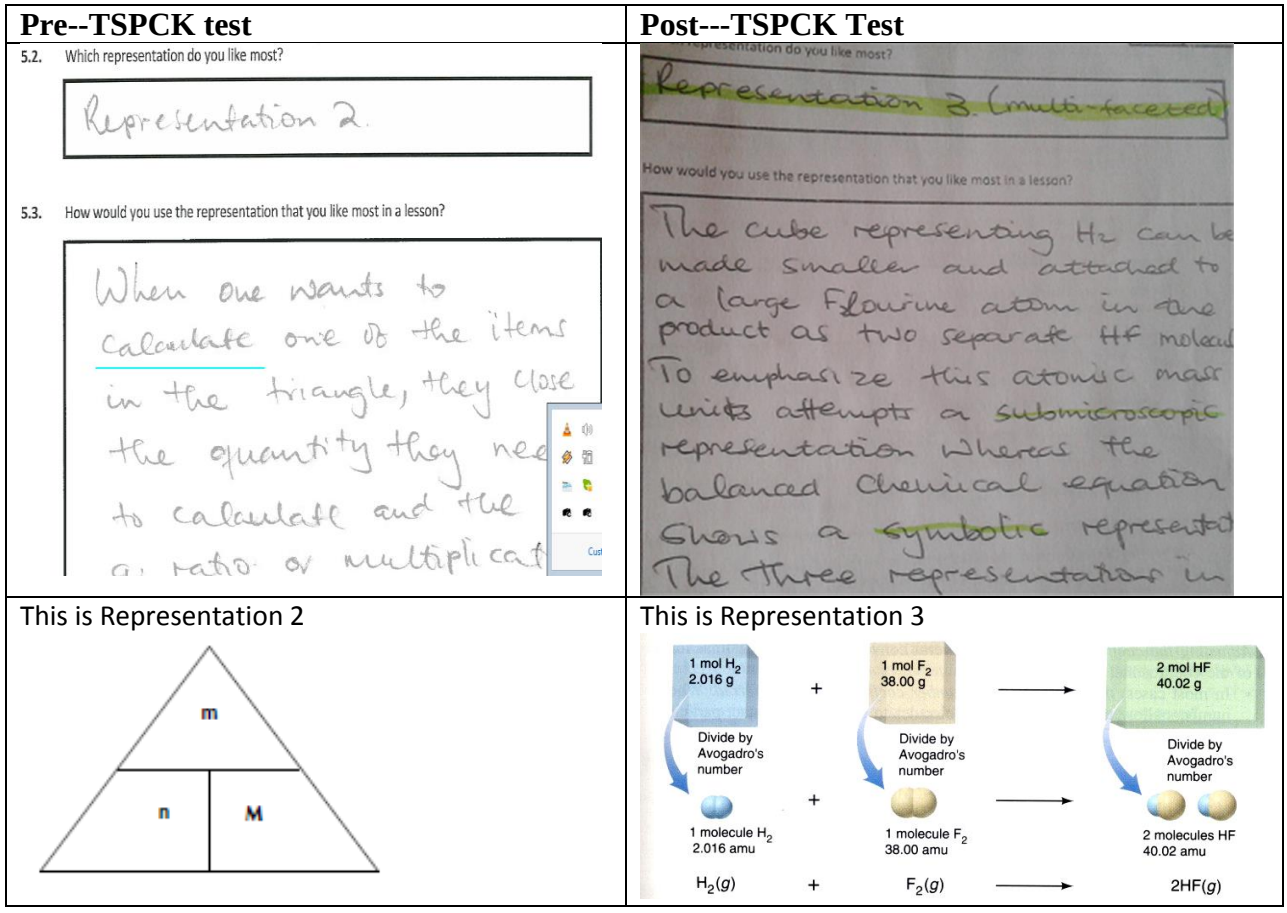


Figure 5.5: An extract from teacher Gigi showing another 2-category improvement in TSPCK

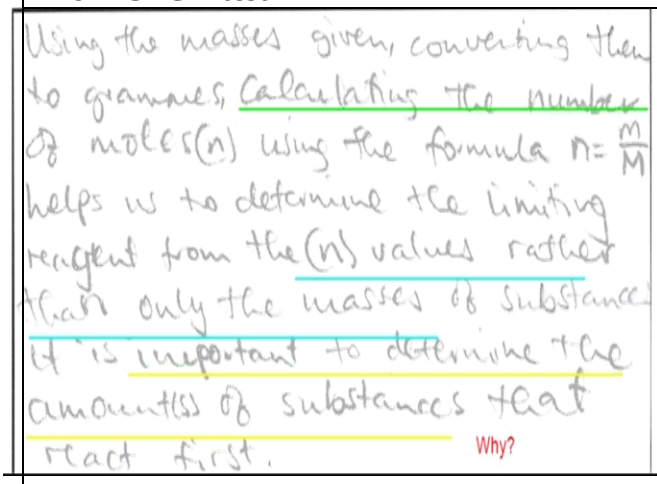
Teacher Gigi's response to the test item on representations and analogies has not been typed out because the scanned documents are clearly written. The first form of evidence in the extract above is the shift towards representation 3, which has multiple representations. Prior to the beginning of the lesson study intervention, teacher Gigi selected Representation 2 as the representation that he likes most. In explaining how he would use the representation in class, the teacher only explains the algorithm of substitution that has no conceptual teaching orientations. Only visual depictions of chemical reactions are shown in the triangle with only symbolic representations of Mass (m), Number of moles (n) and Relative Molecular Mass (M). This shows, according to the TSPCK rubric, a TSPCK quality that is 'Basic' because only a visual representation is used without explanatory notes to make links to the aspects of the concepts considered. A development to category 4, 'Exemplary' TSPCK is noted at the end of the intervention in the form of written Post-test items shown in Figure 5.5. By choosing representation 3, which has the three levels of representations used in chemistry, shows that the teacher now considers the multiple representations in the teaching of the topic stoichiometry. In the Post-test, the teacher further clarifies how he would use the third representation in a lesson.

The cubes for Hydrogen and Fluorine would be made to be of unequal sizes to depict that the atomic sizes of Hydrogen and Fluorine are not the same. The teacher acknowledges that the balanced chemical equation is only a symbolic representation that can be complimented by other representations to foster learner understanding. The presence of explanatory notes that link macroscopic representations to symbolic and submicroscopic representations caused the shift of the TSPCK score from three (3) 'Developing' to four (4) 'Exemplary.' The analysis which follows focuses on a one 1-category shift noted also in teacher Gigi's response on the test item based on the component Conceptual Teaching strategies (CTS).

An example of a 1-category jump in teacher Gigi's responses to a test item on (CTS)

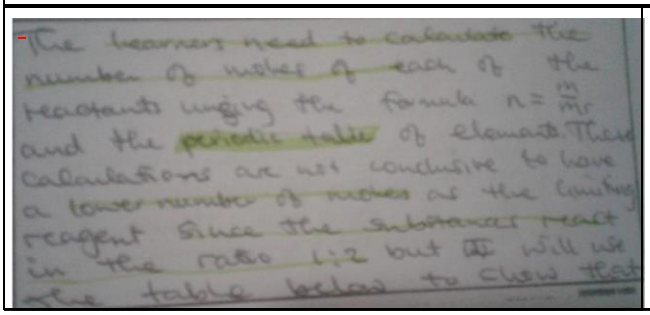
The extract below shows a one 1-category shift in TSPCK for teacher Gigi in the component conceptual teaching strategies (CTS). It is noted in the data that only one of the participant teachers has shown a positive shift in this component, the other two practicing teachers, Alex and Andy did not show a shift in this component. Teacher Andy obtained a score of three (3) in both pre- and Post-tests whereas Teacher Alex obtained a score of two (2) in both pre- and Post-tests in the component conceptual teaching strategies (CTS). Figure 5.6 shows Teacher Gigi's responses to test items on conceptual teaching strategies.

Pre--TSPCK test



Using the masses given, converting them to grams, calculating the number of moles (n) using the formula $n = {}^{m}/_{M}$ helps us to determine the limiting reagent from the n values rather than only the masses of the substances. It is important to determine the amounts of substances that react first.

Post---TSPCK Test



The learners need to calculate the number of moles of each of the reactants using the formula $n = {}^{m}/_{M}$ and the periodic table of elements. These calculations are not conclusive to have a lower numbers of moles as the limiting reagent since the substances react in the ratio 1:2 but will use the table below to show...

Figure 5.6.: An extract from teacher Gigi showing evidence of a 1-category shift in TSPCK

In his pre-test response, the teacher in the extract uses formula explanations without giving reasons why it is important to first determine reacting amounts prior to the determination of limiting reagents showing that when only masses or volumes are used, such information will not be conclusive since the substances react in a ratio of 1:2. A table is used in the Post-test, which is a form of a symbolic representation that is coupled with calculation that shows that after the reaction, there is zero (0) or n of the limiting reagent is used up whilst there is still some amount (n) of the reactant that is in excess left.

The data also shows that there was no improvement in TSPCK in some of the components and there is a need to show an example of a component where a teacher shows no improvement in TSPCK. Figure 5.7 is an extract from teacher Alex in the component conceptual teaching strategies where only teacher Gigi showed the improvement that has been described above. I selected teacher Alex's example because his 'Basic' score of two (2) in this component could have either improved to category three (3) or four (4) because of the intervention but it did not. The TSPCK score for teacher Andy also remained in the 'Developing' category (category 3). Almost half of the components showed no improvement in the interaction of TSPCK components for the practicing teachers. I have selected teacher Alex's responses to items on conceptual teaching strategies (CTS) where the teacher responds to learner misconceptions on the concept of limiting reagents as evidence of no TSPCK development. The excerpt, which is not clear enough in the left column of the figure, has been typed out for the purpose of clarity in the right column. The Post-TSPCK response has been typed out on the next page because the scanned document is illegible.

Evidence of no improvement (Pre- TSPCK test)

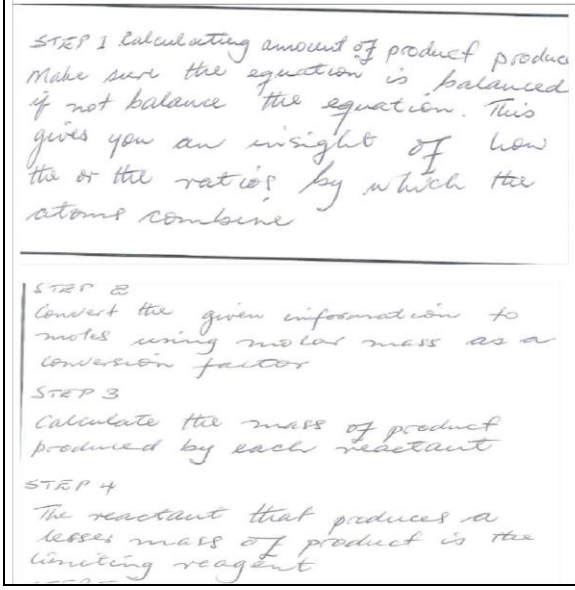
	Step 1. Calculating amount of products, make sure the equation is balanced, if not, balance the equation. This gives you an insight...of the ratios by which the atoms combine. Step 2. Convert the given information to moles using molar mass as a conversion factor. Step 3. Calculate the mass of product produced by each reactant Step 4. The reactant that produces a lesser mass of product is the limiting reagent

Figure 5.7: An extract from teacher Alex that shows no improvement in the TSPCK score.

Teacher Alex maintains the algorithmic approach in using a prescription of steps to solve problems related to limiting reagents. The teacher acknowledges learner misconceptions that are common in the form of balancing chemical equations; however, these misconceptions are not strategically confronted. In both pre- and Post-test responses, there is no evidence of learner involvement in the strategy.

To sum up, I have analyzed the evidence that shows two ways in which the development of TSPCK occurred among practicing teachers during the lesson study intervention. Overall, the practicing teachers showed improvement in their TSPCK as shown in the excerpts discussed in this chapter. The practicing teachers all had high scores in the component Learner Prior knowledge showing that there is consistent integration of this component with other components when the teachers reason out their espoused (planned TSPCK). Teacher Andy had the slightest improvement, having obtained only 2x1-category leap, there were no 2-category shifts in his scores.

Teacher Alex only shows improvement in two components; Curricular Saliency (1-component leap) and what is difficult to teach, where an evident 2-component leap is noted. This 2-component leap has been analyzed in the discussion following Figure 5.3 to show how TSPCK has developed.

Furthermore, the analysis shows how teachers Alex and Gigi experienced 2-category jumps and teacher Andy experienced 1-category jumps in two components. The rest of the scores show either a 1-category leap or no change at all.

5.5.2 Positive shift in the quality of enacted TSPCK in stoichiometry

The findings from the analysis of content of meetings will substantiate the findings about the quality of improvement experienced by the individual teachers in responding to test items in the TSPCK tool. For example, Table 5.2 indicates the frequency of contributions and those contributions that referred or could be linked to the concept of the mole and TSPCK components during video recorded lesson study meetings.

Table 5.2: Frequency of mole related contributions in teacher talk during meetings

	Frequency of contributions that are linked to teaching of the mole			
Participant	**Meeting 1**	**Meeting 2**	**Meeting 3**	**Meeting 4**
Andy	12	9	5	5
Alex	7	10	7	6
Gigi	8	5	5	6

All three participants attended the two-hour meetings except that teacher Andy only missed the first hour of meeting 4. Three teacher educators, an experienced science teachers and researchers together with a colleague who was not part of this study but only there to record the videos attended in all four meetings. The figures in Table 5.2 (page 52) show the number of contributions that are related to the mole from each of the participants across the four lesson study intervention meetings. Each meeting lasted for about two (2) hours and they were held at intervals of one week apart except during the university's mid-semester break when there were no meetings for two consecutive weeks, after which the cycle of meetings and lessons resumed. There was no particular trend in the frequencies of the contributions. However, the content of the contributions is analyzed to provide supplementary data to the increase in the TSPCK scores. Table 5.3 shows the actual verbatim statements of each of the participants from which evidence of TSPCK development is observed to support the findings from the TSPCK tool on stoichiometry.

Table 5.3: Contributions related to TSPCK

Content of contributions that made reference to or with evident links to TSPCK components				
Partici-pant	**Meeting 1**	**Meeting 2**	**Meeting 3**	**Meeting 4**
Andy	*Ja, I think still on the same concern, like they each could measure the amount of stuff in terms of mass . Did they get any…were there any deviations in terms of the mass of the stuff that they weighed?*	*Ja, it took very long. And I think, especially the practical activities, they are not used to doing the practical. So they… where to use mass and remove …* *It's about the number. Size…*	*…important…we check the values…they get… doing the experiments… learner… calculation of a mole… calculating the number of moles of Sulphur and he used 32 grams of…(RP) and he got one (1)…*	*…of those questions, we rarely use those representations in normal teaching.* *Draw the diagram on the chalk board and those representations of the particles inside the… (1:50 minutes).*
Alex	I think the whole lesson (5:33 minutes). But for the sake of time, I thought maybe… put the five substances (?) so that they would ask the	Because when you asked why do we get different masses? What I thought you were saying is that Sulphur is finer. I thought you were talking of a state of	Like now we are doing acids and bases, and I was talking about (?) referring to amount.	Who want to know where learners are struggling...from the pre-test, you know there are misconceptions. But my learners. There are misconceptions I cannot

Alex	same, take this amount of substance you walking around during the lesson.	division		say (9:57 minutes) I did identify those ... ..used to teach these things we only talk about number of moles. And now we're talking about amount of substance. Which is something… that was confusing me, this word… number of moles …number of moles…? Didn't really talk about the amount of substance. So to me it was an eye-opener, for number of moles instead of amount of substance.
Gigi	Maybe since they were working in groups, is that for each group whatever mass they find is (11: 58minutes) showing that the three or four substances have got different masses.	…writing the names and the heading, mole concept of something that will bring that focus on any ideas of what is going (?) on that day. And if it is written on the chalkboard, then the questions can come now, what do you understand about mole? And (?) amount (?) what is (?), what do you mean by amount? Then after that we can (?) use the activities to...	I saw in the lesson there was a number of calling, answering as a group when they say, when the teacher asks, do you think this is the same amount? Some would say, yes, some would say no.	Question he's talking about, in grade twelve, I saw them answering using actually those number of particles into the table (?) …supposed to convert that to number of moles…Initial number of moles, number of moles… I was thinking that (13: 19) to do the presentations actually linked microscopic to macroscopic. For instance I took that in the lessons that we taught, we were supposed to bring in that TSPCK... especially when... periodic table.

Teacher Andy: Analysis of the TSPCK tools in Table 5.1 show that Teacher Andy did not experience any noticeable overall change from the pre- and Post-tests, however, a noticeable change is seen in two components which are *what is Difficult to understand (WD)* and *Representations (RP).* For the component of Representations, TSPCK scores improved from a 'Basic' score of 2 to a 'Developing' score of 3. Similarly, the supplementary evidence from the meetings shown in Table 5.3 above show in the words shaded that concepts related to the mole as only '*the amount of stuff or the mass of stuff*' in meeting 1 progress to analyzing the '*number* 'of particles in Meeting 2. There is also reference to particle '*size'* in meeting 2, which is shaded in green. In Meeting 3, which is shaded in yellow, teacher Andy is getting involved in a discussion that involves salient features of the curriculum in the form of calculating the number of moles. Further qualitative evidence of Teacher Andy's development in Representations is discussed as he is involved in a similar segment in a classroom setting that is also discussed in the next segment of this analysis. In the segment transcribed in Table 5.3, Andy emphasizes that it is '*important to check the values they get whilst they are doing experiments*' referring to an incident in the video when one learner measured 3.2g of Sulphur but went on to the chalkboard and mistakenly substituted 32g into their calculation for the number of moles instead 3.2g of Sulphur in the equation $n = m/M$. There is a shift towards positive development in TSPCK as the statements in red show that there is improved use of the components as the lesson study progresses. The use of the term 'Representations' in Andy's talk begins to emerge into the discussions in Meeting 4. He talks about drawing 'representations of subatomic particles', which is a difficult concept as these are minute particles that cannot be seen with the naked eye. Close analysis of Teacher Andy's Post-test response on the component of what is difficulty (WD) to understand also show that Avogadro's number is 'too big' a number for learners to imagine. An analysis of the combined verbatim transcriptions of Teacher Andy shows an overall improvement in the integration of TSPCK components with the progress of the intervention as the teacher increasingly integrates the components what is difficult to teach (WD) with different representations (RP) that range from submicroscopic (electrons), microscopic and macroscopic representations in his talk during meeting 4 (Table 5.3) when he refers to '*...those representations of the particles inside the…' (1:50 minutes).*

Teacher Alex: also shows a developed engagement with TSPCK components. In Meeting 1, he refers to a teaspoonful of different substances as the same amount of substance and in Meeting 2 he enquires about the use of zinc powder or zinc granules in the experiment as a potential source of misconception as learners are likely to think that the state of division of a substance could be a reason for its lightness or heaviness. Teacher Alex acknowledges the existence of learner misconceptions in Meeting 3 in saying that *'learners are struggling with* misconceptions' and that he is identifying these misconceptions. The teachers engage with a Content Representation or CoRe's (Loughran et. al., 2004) during lesson preparations that enable them to identify and sequence the big ideas in a topic. Teacher Alex admits towards the end of the lesson study that the approach has been an 'eye opener' to him as he now uses the term 'amount of substance' instead of 'number of moles.' This means that the teacher now realizes that a teaspoonful of

different substances does not have the same amount of substance. The realization of misconceptions, their identification and the difficulty of teaching the mole are observed components in the meeting discussions. When the progress seen in teacher Alex in the content of the meetings is compared to the scores in the TSPCK tools, it is observed that Teacher Alex experienced an overall shift from 'Basic' to 'Developing' TSPCK with noticeable shifts in the components of Curricular Saliency (CS) and a 2-category jump in the component of what is difficult (WD) to understand. The component 'what is difficult' to understand is underpinned by the ability to discern most important concepts, knowing what is core and what is peripheral as demonstrated by teacher Alex in his new emphasis of what to talk about in a lesson i.e. number of moles vs. amount.

Teacher Gigi suggests in Meeting 1 that the groups measure the masses of a spoonful of each of the four substances (Zinc, Sulphur, Iron and water) and compare whatever the masses they obtain. In Meeting 2, he suggests that the heading 'The Mole Concept' should be put up and questions relating to the amount of substance can then follow. In meeting 3 he is involved in a discussion about representations of a dozen and a pair used in teacher Alex's lesson which enlightens the group about the misconceptions that learners possess about common units such as a pair and a dozen, making the mole even more abstract to conceptualize. In meeting 4, Teacher Gigi begins to incorporate the use of 'Representations' in his contributions by referring to microscopic and macroscopic representations in a grade 12 examination paper where learners were required to calculate the mass of carbon dioxide produced from the decomposition of a given mass of Calcium Carbonate. A demonstration of the experiment is considered as both a macroscopic representation as well as a teaching strategy that enables conceptual understanding in the leaners, moreover, the discussion in the meeting went on to review the difficulty in finding the mass of a gas. It is difficult to measure the mass of a gas, and so is the teaching of its amount. The components of TSPCK identified in meeting 4 for teacher Gigi include Curricular Saliency (CS), what is difficult (WD) to understand and representations (RP). When comparing the scores of Gigi in the TSPCK scores it is seen that he experienced an overall improvement from 'Basic' to 'Developing', and with the largest shift seen in the component of Representations (RP), where there is a 2-category improvement.

To sum up, the lesson study based intervention had a positive influence on the quality of planned TSPCK in stoichiometry on all three teachers. The influence emerged through different TSPCK components for the participant teachers. Some experienced improvements in only two components, where the improvement in the one component could be different or similar to that in the second component. One teacher experienced an improvement across four components, one of these being a two-category jump (teacher Gigi, Table 5.1). The observed improvements in the TSPCK tools could be collaborated with evidence of shifts of emphasis or interaction of components in the contributions made by the teachers during the lesson study meetings. Thus, it appeared that the teachers experienced growth in the quality of planned TSPCK through different TSPCK components. In the discussion below, I now look for evidence of enacted TSPCK in

their classroom teaching.

In this section, I analyze the data for the presence of TSPCK that emerges in teacher talk in the lessons that were taught during the lesson study. The verbatim statements of the teachers are analyzed for evidence of TSPCK episodes using the rubric developed for enacted TSPCK in Chapter 4. The rationale for the development of a rubric to capture enacted TSPCK has been discussed in section 4.1 (Chapter 4). The purpose of the rubric development has been to enable the researcher to capture the episodes of TSPCK as they occurred in the lessons. Table 3.3 (Chapter 3) shows that the lessons of the three teachers were staggered at weekly intervals and each teacher was exposed to a different number of lesson study meetings prior to their lessons. For instance, teacher Andy, who taught first, was only exposed to one (1) meeting before his lesson. Teacher Alex had been exposed to two meetings prior to his lesson whereas Gigi had three intervention meetings before he taught his lesson. All three teachers taught their lessons outside school hours. Each lesson was conducted over a period of up to 2 hours with short breaks almost every 30 to 40 minutes. The TSPCK episodes in the transcribed lessons were identified in consultation with two other raters. The process followed was first to confirm a teaching segment as a TSPCK episode following the operational definition given earlier in Chapter 3, then the components present identified as well as the kind of interaction observed. All these were then captured as TSPCK maps (Park and Chen, 2012), and the TSPCK episodes graded according to the rubric for enacted TSPCK as seen in Table 5.4.

Table 5.4: Rubric for analysis of enacted TSPCK

Type 1: Basic	**Type 2: Moderate**	**Type 3: Proficient**
• These are simple 2-component TSPCK episodes**.**	• These are 3- component TSPCK episodes.	• These are 4- component TSPCK episodes.
• The two components interacting are clearly, explicitly distinguishable	• The three components interacting are clearly, explicitly distinguishable	• The four components interacting are clearly, explicitly distinguishable
• Both components work together to support an explanation of a single or pair of concepts that are related	• The three components work together to support an explanation of a concept that is implied and not explicit in the episode	• All four (4) components work together to support an explanation of a concept

The overall numbers of TSPCK episodes across the lessons of the three teachers are shown below in Table 5.5.

Table 5.5: Overview of evident TSPCK episodes in the teaching of participant teachers

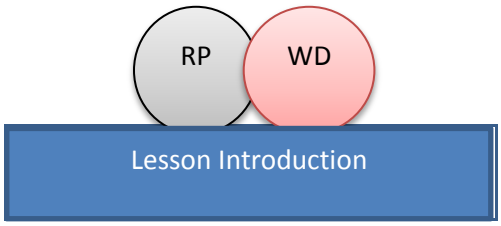
Teacher	Total number of TSPCK episodes evident in lesson	Number of each type of Episode		
		Basic	Moderate	Sophisticated
Andy	5	2	2	1
Alex	6	2	3	1
Gigi	6	2	2	2

The three participating teachers were found to have TSPCK episodes spread largely across 'Basic' and 'Moderate' TSPCK episodes; there is evidence of one or two sophisticated episodes, though. Teacher Andy taught the first lesson after he had been exposed to one lesson study meeting (see Table 3.3). His lesson, as shown in Table 5.5 has the same number (2) of the 'Basic' and 'Moderate' TSPCK episodes, and not as different from teacher Alex who has the highest number of moderate episodes (3). Teacher Gigi has the highest number of 'Sophisticated' episodes (2). The greater number of the TSPCK episodes identified in teacher Alex's lesson is type-2 episodes (Moderate). I report on one of his type-2 episodes as an example of a moderate episode from the participant who has been exposed to 2 lesson study intervention meetings before teaching his lesson on the mole concept. Lastly, out of the 6 episodes identified in Teacher Gigi's lesson; which are equally spread across the three types of episodes. I have selected his type-3 episode (sophisticated) as an example of a TSPCK episode with 4 components interacting to explain a concept. The following section discusses each of the selected examples of the episode types identified in the lessons of the practicing participant teachers.

Examples of TSPCK episodes from each episode type/category

Table 5.6 shows a transcribed segment from teacher Andy's lesson, which is an example of a 2-component TSPCK episode considered to be a 'Basic' TSPCK episode when rated according to the rubric for enacted TSPCK. The rating was done together with a teacher education researcher who is familiar with the TSPCK field of research and the drawing of TSPCK maps. Where there were disparities in the scores, the supervisor gave a third opinion and then we would agree on the final score. A third opinion was needed to confirm the scores since I scored myself, I had to ensure that I am not biased and there is a need for conceseus in judgement. An inter-rater reliability of 80% ensured that the generated results met the accepted criterion; out of the 20 items scored, both raters agreed on an average of 16 scores.

Table 5.6: An example of a 'Basic' or type-2 TSPCK episode

What is happening (41:55 minutes)	**Transcribed teaching segment**
The teacher asks the learners to measure or weigh three grams (3g) of four different substances (Sulphur, water, Sodium Chloride and Zinc) (RP) and asked them if they are the same amount (WD) in terms of the number of spatula loads made by the mass of 3g.	**Teacher Andy:** '…so for Sulphur you added a lot of spatulas to get to three grams (3g) but for Iron only a few spatulas...' (WD) *Teacher says this in response to a group of learners whose answer was 'we added a lot of spatulas of Sulphur than Iron to get to a mass of 3g'* **Teacher Andy:** '…so we cannot conclude that iron is the lightest...?' **Teacher Andy:** '…meaning that those substances of the same mass have different amounts…?'(WD)
TSPCK MAP  *RP=Representations WD=what is difficult	

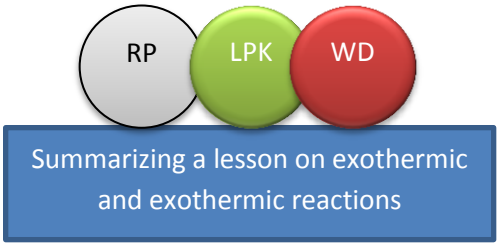
Discussion

The teacher brought in four substances into the class, Sulphur, Iron, Zinc and water which are examples of submicroscopic representations (RP). The learners weigh out 3g of each of the substances to establish if they will be the same '*amount'* in terms of the number of spatula loads. The learners discover that they need more loads of Sulphur than Iron to get to the same mass of 3g. The substances are not the same amount in terms of the number of spatulas and the question can be rephrased to 'does 3g of Sulphur contain the same amount as 3g of Iron? Or any of the other substances used in the investigation. When they discover that they do not give the same number of spatula loads, the teacher consolidates the explanation by concluding that 'substances of the same mass have different amounts' (WD). The two components RP and WD integrate in the explanation of the concept of the 'amount' of chemical substance.

Due to exposure to only one lesson study intervention meeting, most of the episodes in teacher Andy's lesson are either 2 or 3-component episodes. Andy had an equal number of 2 and 3 component episodes which indicate basic and moderate enacted TSPCK respectively. I have used one of his 2-component TSPCK episodes to show that the teacher with the least exposure to the lesson study intervention meetings at the time of going to teach has the least use and integration of enacted TSPCK episode types on average. Such a TSPCK episode is categorized as 'Basic' according to the rubric for the analysis of enacted TSPCK (Table 5.3).
Since teacher Alex had the majority of his episodes in the type-2 or 'Moderate' TSPCK episodes, which consist of three components and has been exposed to 2 lesson study intervention meetings at the time of going to teach, I have selected one of his 3-component episodes to depict the nature of a 'Moderate' enacted TSPCK episode. Figure 5.6 shows an example of a 3-component and 'Moderate' enacted TSPCK episode from the lesson of teacher Alex.

Table 5.7: An example of a 'Moderate' TSPCK Episode

What is happening (10:45 minutes)	**Transcribed teaching segment**
The teacher tabulates some basic physical quantities (symbols and their units) on the (RP) chalkboard. He tabulates the quantities time, displacement and amount of substance (LPK). But focuses on explaining the amount of substance and how it is considered a basic unit for measuring the amount of any chemical substance.	**Teacher Alex: '**What comes to your mind...?' (11:00) *Learner: Money* Let us say...amount of water, amount of salt... (RP)

	The table continues on the next page, showing how the teacher uses a macroscopic representation. **Transcribed teaching segment**
	Amount...(*Lifting the beakers with each of the substances he mentions)*
	*'...*amount of gas*...'(lifting* a *inflated balloon)* (RP)
TSPCK Map  	

*RP=Representations LPK=Learner Prior Knowledge *WD= what is difficult to teach

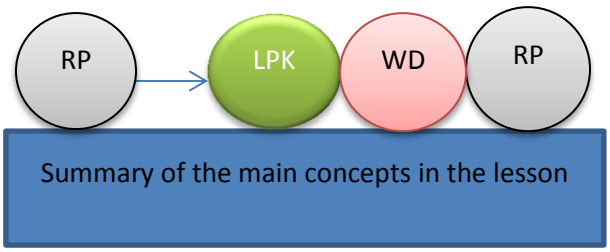
Discussion

When the teacher puts SI units and their symbols onto the chalkboard, he makes use of symbolic Representations (RP) of the concept of the mole that he is teaching. Asking the learners what comes to their minds when they hear the term 'amount' is an attempt by the teacher to establish the prior knowledge (LPK) of the learners or if the learners have any misconceptions. The learners think of money but the teacher brings them to the context of the chemistry class by asking them to describe amount in terms of the different chemical substances (WD) that he has in class. At this juncture the learners have divergent answers ranging from numbers or totals but not giving the correct conception until the teacher uses a practical activity to show that different substances can have the same mass but different amounts because the amount relates to the specific substance whose amount is being determined such as its relative formula mass.

Teacher Gigi had the episodes identified in his lessons evenly distributed among the three categories of episodes. However, because he had the highest number of 4-component episodes (type 3 or sophisticated); out of the 6 episodes identified in his lesson, two of them had 4 components linked together in explaining a single idea or a pair of related concepts. Table 5.8 shows an example of a 4-component TSPCK episode that was identified in teacher Gigi's lesson;

it should be noted that he had been exposed to three lesson study intervention meetings before teaching the lesson (see Table 3.3). The 4-component TSPCK episode are categorized as 'sophisticated' TSPCK episode in the enacted TSPCK rubric, hence it integrates the highest number of components, ideally bringing about the most pedagogic competences to the teaching of the topic.

Table 5.8: An example of a 'Sophisticated' TSPCK episode

What was happening	**Transcribed teaching segment**
The class had completed an activity of finding the masses of a dozen 5c and a dozen 10c Coins (RP). Learners had discovered that the 5c coin weighs more than the 10c coin. The teacher then distributes job cards showing diagrams of subatomic structures of (LPK) compounds the learners have in class (Zinc, Sulphur, water and Sodium Chloride (RP) showing the protons and neutrons and asks learners to determine the mass of one mole of each of these substances.	**(42:39 minutes)** **Teacher Gigi:**'…coins of different sizes, even if they are the same number, they will not give us the same mass' (RP). **Teacher Gigi: "**…and if I had 1 mole of different substances, will they give me the same mass... 1 mole of Hydrogen and 1 mole of Carbon…will they give you the same mass…?"(WD). *Learners: 'No!'* Teacher: "Why?"
TSPCK Map	

*RP=Representations LPK=Learner Prior Knowledge *WD= what is difficult to teach

Discussion

The teacher explains that 1 mole of different substances will not have the same mass. He begins with a demonstration that uses coins (sub-microscopic) representations (RP). He then asks the learners if 1 mole of different substances such as Hydrogen and Carbon will have the same mass. The very small sizes of atoms make it difficult (WD) to understand and conceptualize the size of 1 mole of substances. The teachers' use of coins in the activity shows the teachers use and knowledge of the component LPK since when learners think of amount what comes into their minds is the amount of money rather than rather than chemical substance. To link the microscopic to macroscopic representations, the teacher uses the job cards showing protons and neutrons, the microscopic elementary entities that account for the molar masses of substances, which the learners have in class (macroscopic representations). This episode has been considered a sophisticated TSPCK episode with three distinguishable components interacting clearly to explain a concept. The three components interact clearly and one of the components (RP) is repeated and distinguishable.

Teacher Gigi's lesson, the last lesson in the intervention has the highest number of sophisticated TSPCK episodes which show the explicit interaction of 4 components to explain why different substances will have different amounts of substances even if their number counts in terms of mass may appear to be the same. Having been exposed to three lesson study intervention meetings, teacher Gigi has also shown the highest shift in TSPCK scores in the number of contributions that were related to the mole in meetings (shown in Table 5.7 above). The example of a sophisticated TSPCK episode is drawn from the teacher who taught his lesson after being exposed to three lesson study interventions. I conclude this chapter by summarizing the major findings that have been analyzed here, and looking at the relationships between these findings.

5.6 Summary of major findings

In the concluding remarks to this chapter on data analysis, I will look at the major findings obtained from the TSPCK tool, which provides information on the development of TSPCK as a direct impact of the lesson study intervention. Scores for individual teachers have been analyzed to see if there has been a shift in any one of the components. An overall shift in TSPCK development for the three participants is obtained through the calculation of mathematical averages. The evidence of TSPCK development from the TSPCK scores is supplemented by further evidence of TSPCK development that is obtained from the lesson study intervention meetings. These meetings provide qualitative data because the number of contributions made by each of the participants is observed and recorded, the content of the contributions is analyzed for

reference to the mole and engagement with components of TSPCK. The third and final sources of data were obtained from the classroom practices of the participant teachers. Each of the teachers' video recorded lessons was observed for interactions of TSPCK components.

Findings from the TSPCK tool have shown that at the beginning of the intervention, the average score of the participant teachers was 2 (rounded down from 2.3 since the rubric does not have fractions). This shows that the teachers had TSPCK that is considered 'Basic' according to the rubric that is used for assessing espoused TSPCK. An extract of the rubric for espoused (planned) TSPCK is shown on Table 5.1 and the full rubric is in Appendix 2 (page 94). An average Post-test score of three (3) shows the participating teachers' TSPCK is 'Developing'. The conclusions from these average scores show a positive shift that signifies an improvement in TSPCK component integration as a result of the lesson study intervention. The rubric used to assess the teachers' also looks at the extent to which each of the TSPCK components interacts with other components. The average score is a generalization of the development of TSPCK, close analysis of each teacher against each of the components showed that while there was no improvement in other components, the participants showed either a 1-category jump improvement or a 2-category jump improvement in TSPCK scores.

It was not possible to observe an improvement notable in the tool for the component LPK because all the participants had the maximum score of four (4) in both the pre- and post-tests. The practicing teachers are aware of their students' prior conceptions and misconceptions, as they have been teaching physical sciences at Grade 11 for at least five (5) years (Table 3.1). The practicing teachers TSPCK is exemplary in this component but not in the rest of the components as observed in the findings from the analysis of the individual TSPCK scores. The next paragraph is a summary of the observed individual scores of the three participant practicing teachers in the components in which they showed either a 1 or 2-category improvement in their TSPCK scores.

I begin with a summary of the scores of Andy who showed only 1-category improvements in the components WD and RP. In the component WD, Andy had a pre-test score of 3 (Developing) and a Post-test score of 4 (Exemplary). The shift in TSPCK scores is evidence of TSPCK development for Andy because of the lesson study intervention. In the TSPCK tool, a diagnostic question is asked where learners are required to identify a cube that contains a pair of substances with 1 mole. In the pre-test, Andy only states that one mole of gas occupies 22.4 dm^3 which is the molar gas volume but further stresses o*nly'* for gases in the Post-test further showing that he is aware that learners may have the misconception that any substance, including solids and liquids will occupy a volume of 22,4 dm^3. Andy also shows another 1-category improvement in TSPCK scores in the component Representations (RP) that has a 'Basic' TSPCK score of 2 prior to the intervention which shifts to a 'Developing' score of 3 after the intervention. In the

component ‘Representations’, Andy is aware of the multiple representations in the pre-test as his choice of the third representation shows all the three representations (microscopic, sub-macroscopic and symbolic) in chemistry which he only makes reference to in his Post-test response to the tool. However, Andy did not show any improvement in the TSPCK scores for the other three components LPK, CS and CTS.

Teacher Alex showed improvement in only two of the five TSPCK components. The difference with Andy is that Alex had a 1-category increase in the component CS and a 2-category jump in the component WD whereas both of Andy’s shifts were 1-category jumps. I sum Alex’s 2-category jump in the component Representations as an example of a positive shift in TSPCK scores that show development of TSPCK because of the involvement in the lesson study. At the beginning of the intervention, teacher Alex’s response to the test item on representations shows that he gives a representation that is only symbolic and algorithmic for the calculation of the number of moles by closing a triangle part with a thumb (Representation 2, Question 5 of the TSPCK tool in Appendix 1). The post-test response shows that Alex considers the component LPK by referring to a number of representations from everyday life such as a dozen eggs, oranges or people. This shows the use of RP and LPK and an integration of TSPCK components after exposure to the lesson study intervention.

Gigi showed an improvement in four of the five TSPCK components, with three 1-category jumps and a single 2-category jump. The two-category jump is in the component Representations while the three 1-category jumps are in the components CS, WD and CTS. Gigi is the only participant in the study who registers a positive shift in the component conceptual teaching strategies (CTS) since the other two teachers did not show any improvement in CTS. The pre-test responses for this component show a ‘Basic’ TSPCK engagement for Gigi before treatment. Gigi only uses symbolic representations and algorithms for the calculation of the number of moles. The Post-test response shows that the teacher also recognizes LPK in stating that’ *learners need to calculate the number of moles’.* Reference to the periodic table and formulae shows the use of symbolic representations (RP) together with LPK.

The data from the TSPCK tool is supplemented by the data obtained from the analysis of videos recorded during the planning and discussion meetings that occurred during the lesson study. The frequency of contributions relating to the mole concept is recorded and each of these contributions is analyzed for the use of TSPCK components. The data obtained in this way shows that as the lesson study intervention progressed, there was increasing engagement with the TSPCK components by the participant practicing teachers in the study.

The final part of the analysis answers the second research question and the data points to the increasing interaction of TSPCK components in classroom teaching because of increased exposure to lesson study intervention meetings. There is evidence of this observation in the

comparison of the categories of TSPCK episodes observed in the lessons of the participants. Andy taught the first lesson in the cycle and only had one proficient enacted TSPCK episode in his classroom teaching. The other observed episodes in Andy's teaching are two (2) 'Basic' episodes and two (2) 'Moderate' episodes. The total number of episodes in the teaching of Andy is five (5) and the smallest among the participants. Although Alex also had only one (1) proficient enacted TSPCK episode, he had three (3) 'Moderate' and two (2) 'Basic' enacted TSPCK episodes. This is because he had been exposed to two (2) lesson study intervention meetings before his lesson. The total number of TSPCK episodes identified in his class is six (6), a digit higher than the number of episodes identified in Andy's class. Gigi, having been exposed to three (3) lesson study intervention meetings has the highest number of 4-component interactions that are considered to be 'Proficient' TSPCK episodes when categorized according to the rubric for enacted TSPCK (Table 4.10). The findings from this chapter show that there is an overall improvement and development in TSPCK because of the involvement of practicing teachers in a lesson study. The developed TSPCK can be translated into the classroom teaching of the participants as more TSPCK episodes are seen in the lessons of the participants with the biggest exposure to the intervention meetings. The next chapter, Chapter 6 provides a summary of this study, conclusions to this research study and draws recommendations from the findings that may guide future research on topic specific pedagogy.

CHAPTER SIX

6. Conclusions and Recommendations

6.1 Overview of the study

In this chapter, I begin by providing a brief summary of what this study is about. I move on to relate the findings of this study to the two research questions asked in Chapter 1 to guide the course of this study. I also discuss the implications of the findings and show the value of the conclusions I have drawn from the findings. Recommendations and suggestions are made based on the findings and it is hoped that these recommendations will be used in future studies. This chapter is concluded with a discussion of the limitations of the study and a brief description of the personal reflections that I have made on the study.

6.2 Brief summary of the study

This study is about examining the development of Topic Specific Pedagogical Content Knowledge (TSPCK) among three practicing teachers through their involvement in a lesson study. The lesson study focuses on the transformation of TSPCK improvement gained from a lesson study intervention into the teaching of a specific topic, 'stoichiometry and the concept of the mole' in particular. Physical science results have been consistently poor in South African schools with the majority of candidates at Matric getting poor marks (Table 1.1: Extract from the 2014 Matric examination diagnostic report) especially in questions dealing with stoichiometric calculations including the mole. There is therefore a need for science teachers to employ conceptual teaching strategies that enable learners to understand the content they are taught instead of following conventional algorithms without conceptual understanding. This can be done through teaching stoichiometry thoroughly at Grade 10 and 11 and including the topic in teacher development (DBE, 2013; 2014) programmes and interventions. It has also been noted in literature that TSPCK can be measured among science teachers to develop and improve their teaching practice and to identify areas for teacher support and development (Kind, 2009). In this chapter, I also summarize the findings of the research, which has been guided by the following research questions:

1. How does a lesson study on stoichiometry influence the development of TSPCK in the topic of three practicing teachers?

2. How does the TSPCK developed in stoichiometry translate into practicing teachers' classroom practices?

In the discussion that follows, I answer each of the research questions directly, one after the other.

6.2.1 How does a lesson study on stoichiometry influence the development of TSPCK in the topic of three practicing teachers?

This section explains how the first research question has been answered using the shifts in the TSPCK scores obtained collectively by the three participant teachers and also on analysis of their individual scores obtained from the nature of their engagement with the five (5) TSPCK components. Supplementary evidence obtained from the contributions made by the participant teachers during the lesson study intervention meetings also show that there is TSPCK development in stoichiometry in all three participants. The evidence from the meetings is analyzed for contributions that are made by each of the teachers, the use of TSPCK components made in the meetings and the frequency of such contributions is enumerated to examine how the intervention influences TSPCK development.

The TSPCK achievement tool is a validated tool in which respondents answer semi-structured questions relating to the teaching of the concept of the mole. The responses of the teachers are scored using the TSPCK rubric that shows a set of categorized criteria used to measure a teachers' level of PCK (Park et. al., 2008). The rubric was also adopted by Mavhunga (2012) to capture TSPCK in the topic 'chemical equilibria' among preservice teachers. Ndlovu (2013:41) considers the rubric to be 'reliably measuring specific qualities of PCK to evaluate the whole construct.' The content of the tool relates well to the topic stoichiometry and raises pertinent issues about the mole; a construct that has been considered tacit in an article by Nelson (1991) entitled 'The elusive mole.' Questions are asked about the nature of the mole and what makes it difficult to comprehend, how best it can be taught, what representations can be used to effectively depict the mole.

The findings from the TSPCK achievement tool show an overall improvement in the TSPCK scores from a pre-test average score of 2 to a Post-test average score of 3. The TSPCK scores of the individual participants also show a similar improvement for some of the components while other components had scores that remained the same. The conclusion therefore is that TSPCK is developed through the involvement of practicing teachers in a lesson study. The evidence of development from the pre- and Post-test TSPCK scores are supplemented by further evidence of development observed in the contributions made by participants in the four (4) lesson study intervention meetings held weekly during the time of the lesson study. Further evidence of TSPCK development is observed in the classroom practices of the participants and has been used to answer the second research question. The summary of the findings that help answer research question 2 are discussed in the following section.

6.2.2 How does the TSPCK developed in stoichiometry translate into practicing teachers' classroom practices?

Analysis of the classroom practices of the three practicing teachers show that the number of lesson study intervention meetings each participant had been exposed to determine the quality of TSPCK episodes observed in their classroom practices. Andy, having been exposed to only one (1) lesson study intervention before teaching his lesson only had the majority of his episodes in the 'Basic' TSPCK and 'Developing' TSPCK categories with only one sophisticated episode. His total number of TSPCK episodes is the lowest with five (5) episodes. The total number of TSPCK episodes in Alex and Gigi were both six (6) as shown on Table 5.5, page 58. However, Alex had more episodes in the 'Basic' and 'Moderate' categories while Gigi had the majority of the episodes in the categories 'Moderate' and 'sophisticated' categories. Gigi had the highest number of 'sophisticated' episodes among the three participants because of the biggest number of lesson study intervention meetings he attended before teaching the lesson. This shows that there is improvement in TSPCK with the more interventions a practicing teacher has. It is evident that the teacher who has attended the highest number of intervention meetings transforms the competences obtained from the lesson study intervention into classroom practices. The contributions of the above findings to new knowledge in science education are discussed in the segment that follows.

6.3 Contributions of study to new knowledge

There is growing literature on instruments to measure TSPCK since the PCK summit in Springs Colorado in October 2012. There has been focus on espoused TSPCK in planning documents to measure teachers' PCK. In the construct TSPCK, which may be traced into classroom contexts, a need has emerged for researchers to be able to capture and measure enacted TSPCK in the classroom practices of the teachers. The development of a rubric for enacted TSPCK enables the measurement of TSPCK located within the pedagogic practices of teachers. Gaps will certainly exist in the literature in both the further improvement of the rubric that has been developed in Chapter 4 and the expansion of topic specific literature to the wide array of topics within the discipline of science and in other learning areas.

The components that showed no improvement in the TSPCK scores of participants may require further exploration in the way that the lesson study is conducted to promote engagement with such components and promote further TSPCK development in stoichiometry. Further development may be explored through linking the topic to submicroscopic representations that promote conceptions of the mole; these can be developed to improve the performance of learners through the bridging of conceptual gaps when knowledgeable teachers teach them. Teachers also need to be equipped with problem solving strategies that may be gained through collective planning and adopting best practice and integration of various teacher knowledge bases that

promote holistic classroom learning. Tullberg et al. (1994) suggest the linking of the concept of the mole to its applications in industry can improve its comprehension. The same sentiments have been echoed in the work of Evans et al. (2006). I review the methodology that I have used in the collection of data as well as the contributions that this study has made to lesson study methodology in the next section.

6.4 Reflections on the methodology used

The lesson study meetings and lessons taught during the lesson study cycle were video recorded for the analysis of the speech of the teachers so that the data obtained from the TSPCK tool is supplemented by evidence from the meetings. The meeting videos are analyzed for evidence of developing TSPCK. The lessons were also video recorded to see if the improvement in TSPCK as a result of the lesson study intervention can be translated into classroom practice. Appropriate tools were found to measure espoused TSPCK but a rubric for enacted TSPCK in the context of the classroom had to be developed in this study.

The complex nature of investigating problems in education necessitated the employment of qualitative research methods to obtain as much information as possible from the research tools and instruments that were employed in this study. The case study has been used as a strategy to obtain detailed information from the individual cases of the three participant practicing teachers.

The iterative meetings in the lesson study are regarded as a treatment in this research, the participant teachers constantly engage with the researchers in weekly meetings to discuss ways of delivering an improved lesson on the concept of the mole by discussing the topic within the framework of TSPCK transformation for learner understanding. The participants are experienced teachers in the teaching of physical sciences who are also conducting studies on PCK and are voluntarily participating in the study. The demonstration of TSPCK in practice has been seen to be dependent on the number of intervention meetings the individual participants attended. An instrument had to be designed in Chapter 4 to capture and measure the quality of TSPCK observed in practice, a rigorous but worthwhile contribution to the research literature on TSPCK. Other contributions of the findings to science education include the implications lesson studies can have for teacher development programmes (DoE, 2006) which are discussed below.

6.5 Implications for teacher development

Considering the elusive and tacit nature of the mole and its importance in understanding other topics such as chemical equilibria; acids and bases; and electrochemistry, there is a need for investment in time for teachers to understand and demonstrate an awareness of versatile representations and teaching strategies to demystify the mole.

Rollnick et al. (2008) have argued that 'a procedural approach is possibly the product of contextual factors such as the demands of external examinations rather than a limited content knowledge.' This means that there seem to be just not enough time to teach the concept of the mole. When teachers rush through completing the syllabus, learners lose out on the opportunities to learn certain topics, learners are best taught through conceptual understanding than algorithms that prepare them to pass examinations and leave school without having benefited conceptually.

The TSPCK tool may also be used as a teacher development tool in both in-service teacher training/development workshops and to prompt preservice teachers' comprehension of the use of TSPCK components.

6.6 Review of validity, reliability and ethical issues

Validity. The TSPCK tool is a validated tool (Rollnick et. al, 2015) since it is used to measure content transformation using items from each of the five TSPCK components of the TSPCK model to specific content knowledge for a particular topic. The TSPCK rubric is criterion based and related to the criteria that are used to measure the development of TSPCK. The components show increasing difficulty between Learner Prior Knowledge (LPK), Curricular Saliency (CS), through what difficult (WD) to teach and Representations and analogies (RP) up to Conceptual teaching strategies (CTS). The findings from this research show that there is no improvement in CTS except for teacher Gigi who shows only a 1-category jump in this component (CTS).

Reliability. The rubric that is used to analyze the TSPCK achievement tool responses of the participant teachers has been used in other studies to trace the development of PCK. The scale of 1 – 4 on the rubric is reasonable to place the items according to the number of interacting components in an analyzed set of data. Akinyemi (2016) has used the rubric with 34 preservice teachers in the physics topic 'kinematics' whereas Ndlovu (2013) argues that the rubric is reliable in evaluating the construct of PCK; Mavhunga (2012) adopted the same rubric for use in TSPCK with preservice teachers in the topic 'chemical equilibria'. The rubric for enacted PCK that I have developed in Chapter 4 is also used in evaluating two other teachers in two other topics that were not part of this study but used to test if the developed rubric can be used in other contexts to give similar results. The analysis in chapter 4 shows that the teachers also showed 2, 3 and 4 TSPCK components interacting.

Ethics. The participant teachers voluntarily took part in the study, nonetheless, all relevant consent forms were signed by the participating teachers, their school principals, learners and their parents or legal guardians. Permission was obtained from the provincial education authorities; the Gauteng Department of Education (GDE), an ethics clearance letter from the Gauteng Department of Education is attached as Appendix VII. The Human Sciences Research

Committee (HSRC) of the University of the Witwatersrand's approval to conduct the study is attached as Appendix VIII and the protocol number is 2015ECE039E.

All participants were informed about the purpose of the study and of their voluntary participation. They were also informed that they could withdraw from the study anytime without any harm or loss. The participants were also guaranteed on confidentiality and anonymity as pseudonyms have been used to identify them in the reporting of the research findings. The data obtained will only be used for research purposes in the form of academic journals or seminar presentations. Raw data is secured and kept under lock and key while electronic data is password secured until a period of between 3-5 years has elapsed when the data can then be destroyed. The next segment of this conclusion chapter looks into the limitations of this study.

6.7 Limitations of the study

The sample of three participating science teacher is too small a sample to generalize the finding that teachers' exposure to a lesson study will improve their TSPCK in a topic such as stoichiometry. A larger sample would have created financial, time and other resource related difficulties, though. The sampled teachers are not fully representative of the demographics of South African science teachers since all three hold Postgraduate qualifications in the teaching of science and are pursuing further studies in science education.

6.8 Recommendations

Chapter 1 has described the lesson study as a vehicle for the development of TSPCK among teachers. The introduction of the Curriculum Assessment and Policy Statements (CAPS) as a new syllabus in 2014 meant that the topic stoichiometry had to be studied from Grade 10. This has placed a burden on teachers who teach grade 10 but are not familiar with stoichiometry. The lesson study approach can be used as a teacher development approach to assist teachers engage with topics that they may not be familiar with or find incomprehensible and difficult to teach. Vokwana's current doctoral study focuses on out-of-field science teachers in the Eastern Cape, showing that there is a lack of suitably qualified teachers to the extent of using teachers trained in other fields to teach science. Such teacher development programmes as the lesson study may target such teachers; engage them with specific topics that help them teach science more effectively. The tools used in this study can be used as diagnostic instruments to find out which areas or topics teachers find difficult to teach and plan for development programmes. Based on the findings from this study, I make the following recommendations for further exploration of topic specific strategies:

6.8.1 Creating baseline knowledge for science teachers in stoichiometry

Topic specific approaches to teacher development could be introduced to larger samples of

science teachers in teacher development programmes to ascertain which TSPCK categories they belong to. In areas where there is very little or no engagement with the topic specific components, such regions should be prioritized when mass training and dissemination of new curricular is rolled out. The findings from the study show that algorithms and procedural approaches to teaching stoichiometry account for the 'Limited' or 'Basic' TSPCK characteristic of some in-service teachers. In the component Representations, all participants had a baseline score of two (2) showing that qualified and experienced teachers also show very little in terms of TSPCK development prior to their involvement in the lesson study. There is limited exploration of possible representations in the teaching of science. The pre-test scores also show that the qualified and experienced teachers showed 'Basic' TSPCK scores in the component curricular saliency (CS), and conceptual teaching strategies (CTS). There is a need in future studies to focus on the improvement in these particular components that link objectives of the curriculum to appropriate strategies for classroom teaching.

The identification of teachers with 'Exemplary' TSPCK in particular components and subjects can help identify suitable facilitators for teacher professional learning communities and teacher development programmes.

6.8.2 Informing curriculum developers on the need to spend more time teaching stoichiometry

It was noted in the study that conceptual teaching strategies require more time to implement. The activities designed for conceptual teaching are time consuming and there is a need for curriculum developers and pace setters to review time allocated to the topic stoichiometry as the baseline knowledge obtained from the topic enhances the understanding of topics in future grades, studies and topics such as chemical equilibria, electrochemistry as well as acids and bases.

6.8.3 Professional learning communities at school, cluster, district or regional levels

The lesson study approach could be harnessed for use by small groups of teachers who need to discuss content in specified topics at the level of either the school, a group of schools within a cluster or even at a larger scale at district or regional levels. The approach encourages collegial processes and the sharing of information that relates to best practice in the teaching of specified topics. Moreover, the study has highlighted that when teacher development initiatives are organized by teachers themselves, they are likely to be more effective than programmes that are imposed on teachers which are likely to be resisted.

6.8.4 Depiction of the mole concept in textbooks

Participants depict the mole as a number or the symbol of the amount of substance prior to the intervention, they expressed that such definitions are given in the textbooks. On the contrast, the

curriculum requires learners to understand that the mole is the SI unit for the amount of chemical substance. The textbooks used in schools need to be qualitatively analyzed for statements that are likely to cause misconceptions in learners (Cervellati et al., 1982). There is also a need for textbook authors to conform to standard definitions that are used in curriculum documents. Further studies may look into the conceptualization of the mole by teachers themselves and the realization of what appropriate learner support materials and teaching aids or resources could be used to foster conceptual understanding of the concept of the mole.

REFERENCES

Akinyemi, O.S. (2016). Pre-service teachers' development of Topic Specific PCK in kinematics and transferability of PCK competence to a new physics topic. University of the Witwatersrand: Johannesburg.

Aydın, S. & Boz, Y. (2013). The nature of integration among PCK components: A case study of two experienced chemistry teachers. *Chemistry Education: Research and Practice. 14, 615-624. DOI:* 10.1039/c3rp00095h.

Aydın, S., Demirdöğen, B., Akın, F., Uzuntiryaki, E., & Tarkın, A. (2015). The nature and development of interaction among components of pedagogical content knowledge in practicum. *Teaching and Teacher Education, 46,* 37-50. doi:10.1016/j.tate.2014.10.008.

Aydeniz, M. and Kirbulut Z. D., (2014), Exploring challenges of assessing pre-service science teachers' pedagogical content (PCK). Asia-Pacific Journal of Teacher Education, 42, 147-166.

Abell, S. K. (2008). Twenty years later: Does pedagogical content knowledge remain a useful idea? International Journal of Science Education, 30(10), 1405–1416.

Ball, D. L., Thames, M. H. & Phelps, G. (2008). Content Knowledge for Teaching: What Makes It Special? *Journal of Teacher Education.* 59, 389.

Berry, A., Loughran, J., & Van Driel, J. (2008). Revisiting the roots of pedagogical content knowledge. International Journal of Science Education, 30(10), 1271–1279.

Beaton, A.S., Mullis, I.V.S., Martin, M.O., Gonzalez, E.J., Kelly, D.L. and Smith, T.A. (1996). Mathematics achievement in the middle school years: IEA's *Third International Mathematics and Science Study (TIMMS).* Chestnut Hill, MA: Boston College.

Boaler, J. (1997). 'Setting, Social Class and Survival of the Quickest'. *British Educational Research Journal*, 23(5), 575-95.

Boyatzis, R. E. (1998). *Transforming qualitative information: Thematic analysis and code Development*. Thousand Oaks, CA: Sage

Cerveliati, A., A. Montuschi, and D. Perugini. (1982). Investigation of Secondary School Students' Understanding of the Mole Concept in Italy. *Journal of Chemical Education. Volume 59,* Number 10: 852-856.

Cochran, K. F., King, R. A. & Deruiter, J. A. (1991). Pedagogical content knowledge: A tentative model for teacher preparation. Paper presented at the annual meeting of the *American Educational Research Association*, 3-7 April, Chicago, IL.

Creswell, J.W. (2012). Educational research: Planning, conducting, and evaluating quantitative and qualitative research. (4th Ed.). Boston: Pearson. pp. 385-401.

Davis, E., & Krajcik, J. (2005). Designing educative curriculum materials to promote teacher learning. Educational Researcher, 34(3), 3–14.

De Jong, O., van Driel, J. H., & Verloop, N. (2005). Pre-service teachers' pedagogical content knowledge of using particle models in teaching chemistry. Journal of Research in Science Teaching, 42(8), 947–964.

DoE. (2011a). National curriculum statement grades 10 - 12: Physical sciences. Pretoria, Gauteng: Department of Education.

DoE (2006). The national policy framework for teacher education and development in South Africa. Pretoria, Gauteng: Department of Education.

Fernandez, C. (2002). Learning from Japanese approaches to professional Development. *Journal of Teacher Education*, 53, 393–405.

Fernandez-Balboa, J., & Stiehl, J. (1995). The generic nature of pedagogical content knowledge among college professors. *Teaching and Teacher Education, 11(3),* 293-306.

Foss and Ellefsen (2002) Foss, C. & Ellefsen, B. (2002). 'The Value of Combining Qualitative and Quantitative Approaches in Nursing Research by Means of Method Triangulation'. *Journal of Advanced Nursing*, 40(2), 242-248.

Fraenkel, J.R., & Wallen, N.E. (2006). *How to design and evaluate research in education.* New York: McGraw-Hill.

Geddis, A. N. & Wood, C. (1997). Transforming Subject Matter and Managing Dilemmas: A case Study in Teacher Education. *Teaching and Teacher Education*, 13(6), 611-626.

Gess-Newsome, J. (1999). Pedagogical content knowledge: An introduction and orientation nature, sources and development of pedagogical content knowledge for science teaching, In J. Gess-Newsome & N. G. Lederman (Eds.). *Examining pedagogical content knowledge: The*

construct and its implications for science education (pp.3-17). Boston: Kluwer.

Grossman, R. (1990). The making of a teacher: *Teacher knowledge and teacher education.* New York/ London. Teachers' College Press.

Hashwash, M. Z. (1996). Effects of science teachers' epistemological beliefs in teaching. *Journal of Research in Science Teaching*, 33, 47- 64.

Howie, S.J. (2003). Language and other background factors affecting secondary school performance in mathematics in South Africa. *African Journal of Research in Mathematics, Science and Technology Education, 7*:1-20.

Jansen, J.D. 2004. Matric quick fixes miss the mark, *Sunday Times*, 4 January.

Johnson, R. B., Onwuegbuzie, A. J., & Turner, L. A. (2007). Toward a definition of mixed methods research. *Journal of Mixed Methods Research*, 1, 112–13

Kaya, O. N. (2009). The nature of relationships among the components of pedagogical content knowledge of preservice science teachers: 'Ozone layer depletion' as an example. *International Journal of Science Education, 31 (7),* 961–988.

Kind, V. (2009). Pedagogical content knowledge in science education: perspectives and Potential for progress. *Studies in Science Education*, 45(2), 169-204.

Lewis, C. Perry, R. Hurd, J. and O'Connell, M. P. (2006). Lesson study comes of age in North America. *Phi delta kappan, 88*(4), 273.

Lewis, E., Dema, O., & Harshbarger, D. (2014). Preparation for practice: Elementary preservice teachers learning and using scientific classroom discourse community instructional strategies. *School Science and Mathematics, 114*(4), 154-165.

Lincoln and Guba Lincoln, Y.S. & Guba, E.G. (1985). *Naturalistic inquiry*. Thousand Oaks, CA: Sage.

Loughran, J. J., Mulhall, P. & Berry, A. (2004). In search of pedagogical content knowledge in Science: Developing ways of articulating and documenting professional practice. *Journal of Research in Science Teaching*, 41(4), 370-391.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.), Examining pedagogical content knowledge: The construct and its implications for science education (pp. 95–132). Dordrecht: Kluwer Academic.

Makgato, M. & Mji, A. (2006). Factors associated with high school learners poor performance: a spotlight on mathematics and physical science. *South African Journal of Education.* Vol. 26(2)253-266.

Malcolm, S. Rollnick, M. and Mavhunga, E. (2014). Conceptualization of the Mole: An Argument for a refined conception of the Mole for Effective Teaching of Stoichiometry in Webb, P., Villanueva, M.G., Webb, L. (Eds). Proceedings of the 22nd Annual meeting of the Southern African Association for Research in Mathematics, Science and Technology Education. NMMU: SAARMSTE vol. 2, 82-88.

Mavhunga, E., & Rollnick, M. (2013). Improving PCK of chemical equilibrium in pre-service Teachers. African Journal of Research in Mathematics, Science and Technology Education, 17(1–02), 113–125.

Mavhunga, E. M. (2016). Transfer of pedagogical transformation competences across chemistry topics. *Chemistry Education Research and Practice:* 1-18.

McMillan, J. H. & Schumacher, S. (2010). *Research in education: Research-based inquiry*. (7th Ed.).Upper Saddle River, NJ: Pearson Education, Inc.

Miles, M., & Huberman, A. (1994). Qualitative data analysis (2nd ed.). Thousand Oaks, CA: Sage.

Moran, R.A. and Butler, D.S. (2001). 'Who's Health Profile?' *Critical Public Health* 11(1), 59-74.

Ndlovu, M. (2013). The design of an instrument to measure physical science teacher's topic specific pedagogical content knowledge in electrochemistry (Unpublished Masters' thesis). University of the Witwatersrand, Johannesburg, Gauteng, South Africa.

Nelson, P. G. (1991). The elusive mole. Education in Chemistry, 28 (4), 103 –104.

Nelson, P. G. (2013). What is the mole? Foundations of Chemistry, 15 (1), 1-9.

Nilsson, P. (2008). Teaching for understanding: The complex nature of pedagogical content

knowledge in pre-service education. International Journal of Science Education, 30(10), 1281–1299.

Nilsson, P. (2014). When teaching makes a difference: Developing Science Teachers' pedagogical content knowledge through learning study. *International Journal of Science Education.* Halmsted University. Halmsted, Sweden.

Opie, C. (Ed.). (2004). Doing Educational Research - A Guide to First Time Researchers. London: SAGE Publications.

Packer, J.E. (1988). Difficulties with stoichiometry. *Education in Chemistry, 25 (3),* 92 – 95.

Park S. and Chen Y., (2012). Mapping out the integration of the components of pedagogical content knowledge (PCK): Examples from high school biology classrooms, *Journal of Research in Science Teaching, 49, 922 - 941.*

Park, S., Jang, J.Y., Chen, Y. C. & Jung, J. (2008). Developing measures of teacher pedagogical content knowledge for teaching school biology. Paper presented at The International conference of the Association for Science Teacher Education, St. Louis, Michigan.

Park, S. & Oliver, J. S. (2008). Revisiting the conceptualization of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. *Research in Science Education 38, 261-284.*

Reddy, V. (2004). TIMMS media briefing. Human Sciences Research Council, 14 December, Pretoria.

Rollnick, M., Bennett, J., Rhemtula, M., Dharsey, N. & Ndlovu, T. (2008). The place of subject matter knowledge in pedagogical content knowledge: A case study of South African teachers teaching amount of substance and chemical equilibrium. International Journal of science Education, 30(10), 1365-1387.

Rollnick, M. (2012). South African presentation at the 2012 PCK Summit. Presented at the PCK Summit: Current and Future Research Directions. Colorado Springs, CO. 155

Rollnick, M. & Mavhunga, E. (in press). The PCK summit and its effect on work in South Africa. In A. Berry, P. Friedrichsen & J. Loughran (Eds.), Re-examining Pedagogical Content Knowledge in Science Education. Abington, UK: Routledge.

Rollnick, M. Bam, N., van der Merwe, D., Zimmerman, G., and Malcolm, S. (2015). PCK Instruments: Are we measuring PCK? Symposium presented to the 22nd Annual Meeting of the Southern African Association for Research in Mathematics, Science and Technology Education. Edwardo Mondlane University, Maputo.

Schmidt, H. J. (1987). Secondary school students' learning difficulties in stoichiometry. In Novak (Ed.), *Proceedings of the 2nd international seminar "Misconceptions and educational strategies in science and Mathematics" (Volume 1)* (pp. 396-404). Ithaca: Cornell University.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. Educational Researcher, 15 (4), 4 –14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. Harvard Educational Review, 57 (1), 1 –21.

Stake, R. E. (1995). The art of case study research. Thousand Oaks, CA: Sage Publications.

Taber, K. S. (2001). Building the structural concepts of chemistry: some considerations from educational research. *Chemistry education: research and practice in Europe, 2*(2), 123-158.

Tashakorri, A. & Creswell, J. W. (2007). The New era of mixed methods. Journal of Mixed Methods, 1 (3), 3 –7.

Van Driel, J., De Jong, O., & Verloop, N. (2002). The development of pre-service chemistry Teachers 'pedagogical content knowledge. *Science education,* 86, 572-590.

Van Driel, J. H. & Berry, A. (2011). Pedagogical content knowledge. In International encyclopedia of education (3rd Ed., Vol 7, pp.656 –659). Amsterdam, Netherlands: Elsevier Science & Technology Books.

Veal, W. R., & Makinster, J. G. (1999). Pedagogical Content knowledge taxonomies. Electronic Journal of Science Education 3(4). Retrieved July 10, 2012 from the World Wide Web: http://ejse.southwestern.edu/article/viewArticle/7615/5382

Vokwana, N. (2016). Investigating the development of Topic Specific Pedagogical Content Knowledge (TSPCK) for out-of-field, rural Natural Sciences (NS) teachers: Fusion of content and pedagogy. Proceedings of the 24th Annual conference of the Southern African Association for Research in Mathematics, Science and Technology Education. TUT: Pretoria.

Yin, R. (1994). *Case study research: Design and methods.* (2nd Ed.). Newbury Park, CA: Sage Publications, Inc.

APPENDIX I-TSPCK TOOL

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

PARTICIPANT TEACHER'S DEMOGRAPHIC INFORMATION

CODE:	

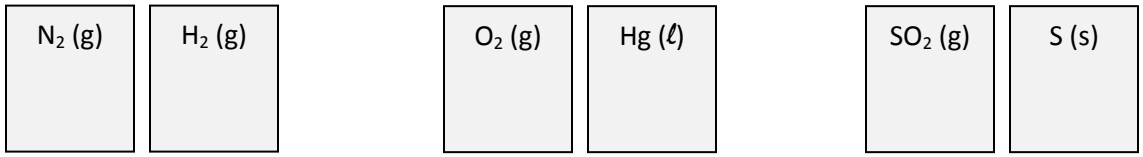
NAME:		
GENDER	Male	Female

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 question 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

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.

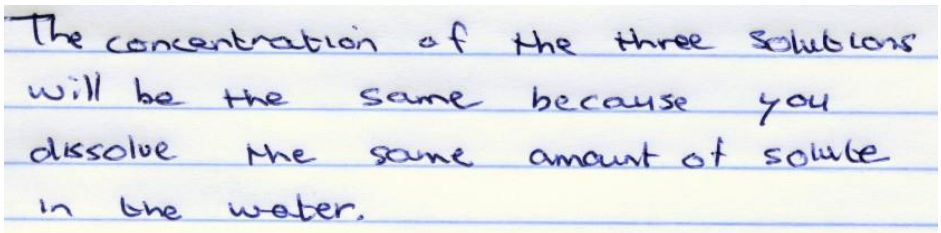
My choice is Response _____

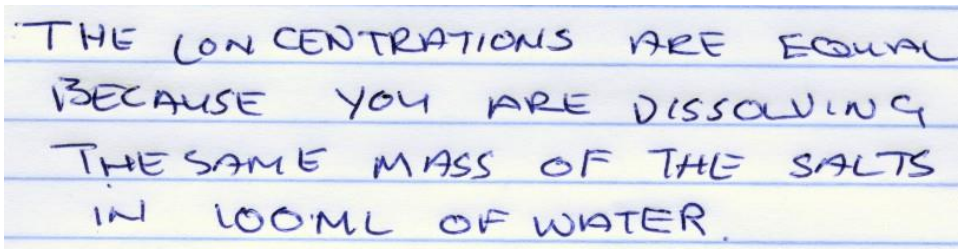
3. After teaching the learners about concentration you give them an exercise to do for homework. In one question you ask learners the following question.

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?





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 work out 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 _____

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 22,4dm^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.

	Suggested concepts and sequence	Reasons
1.		
2.		
3.		

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

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

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 r eason(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		

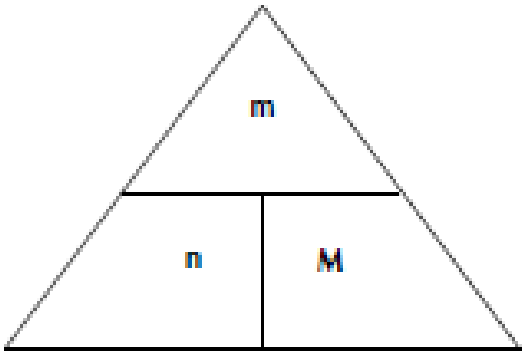
CATEGORY D: REPRE-SENTATIONS/ANALOGIES/MODELS

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

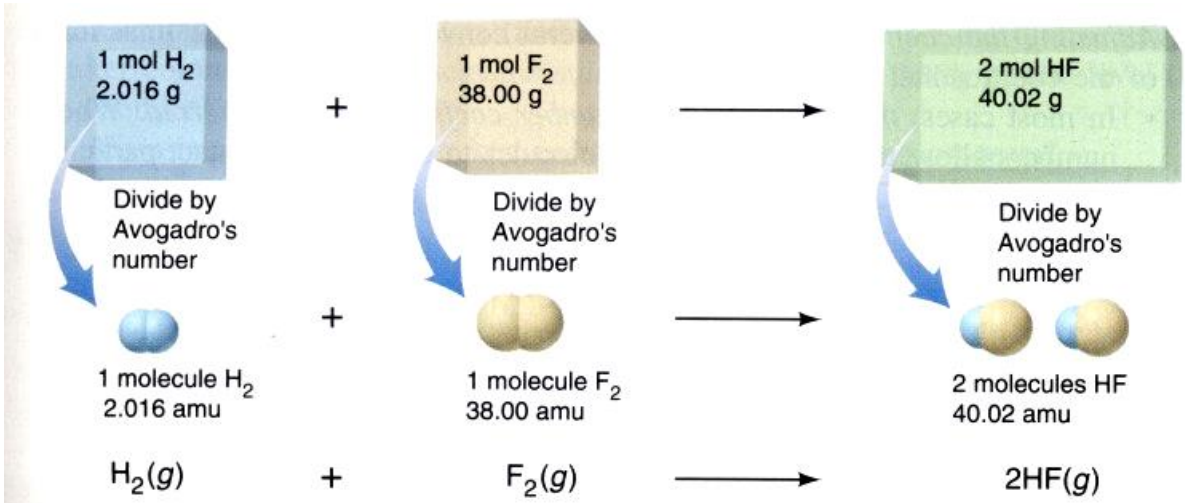
Representation 1

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



Repre-sentation 3

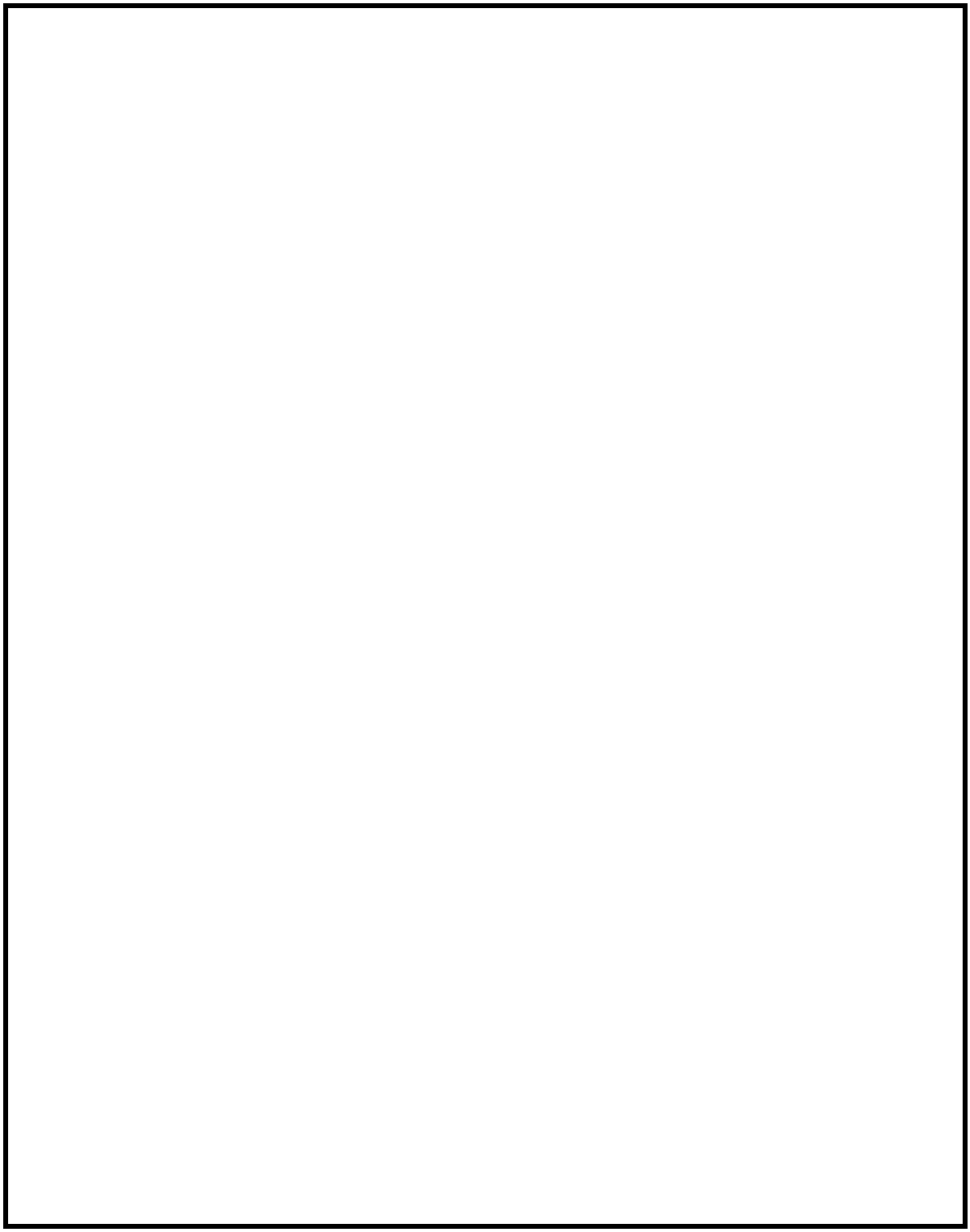


5.1. Complete the table below by providing as many details as possible about each representation.

Representation No.	What I like	What I do not like

5.2. Which representation do you like most?

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



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:

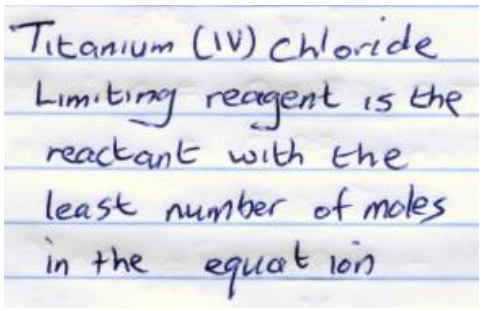
$$TiC\ell_4(g) + 2Mg(\ell) \rightarrow Ti(s) + 2MgC\ell_2(\ell)$$

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.

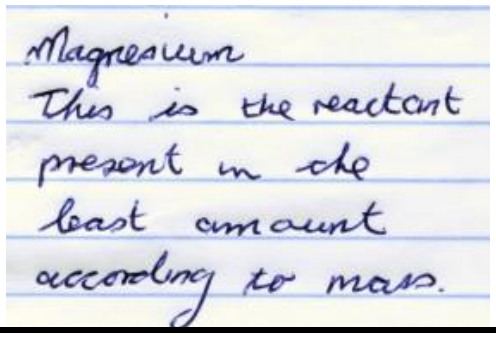
Source: Department of Education (2007). Grade 11 Chemistry Paper, November Examination

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

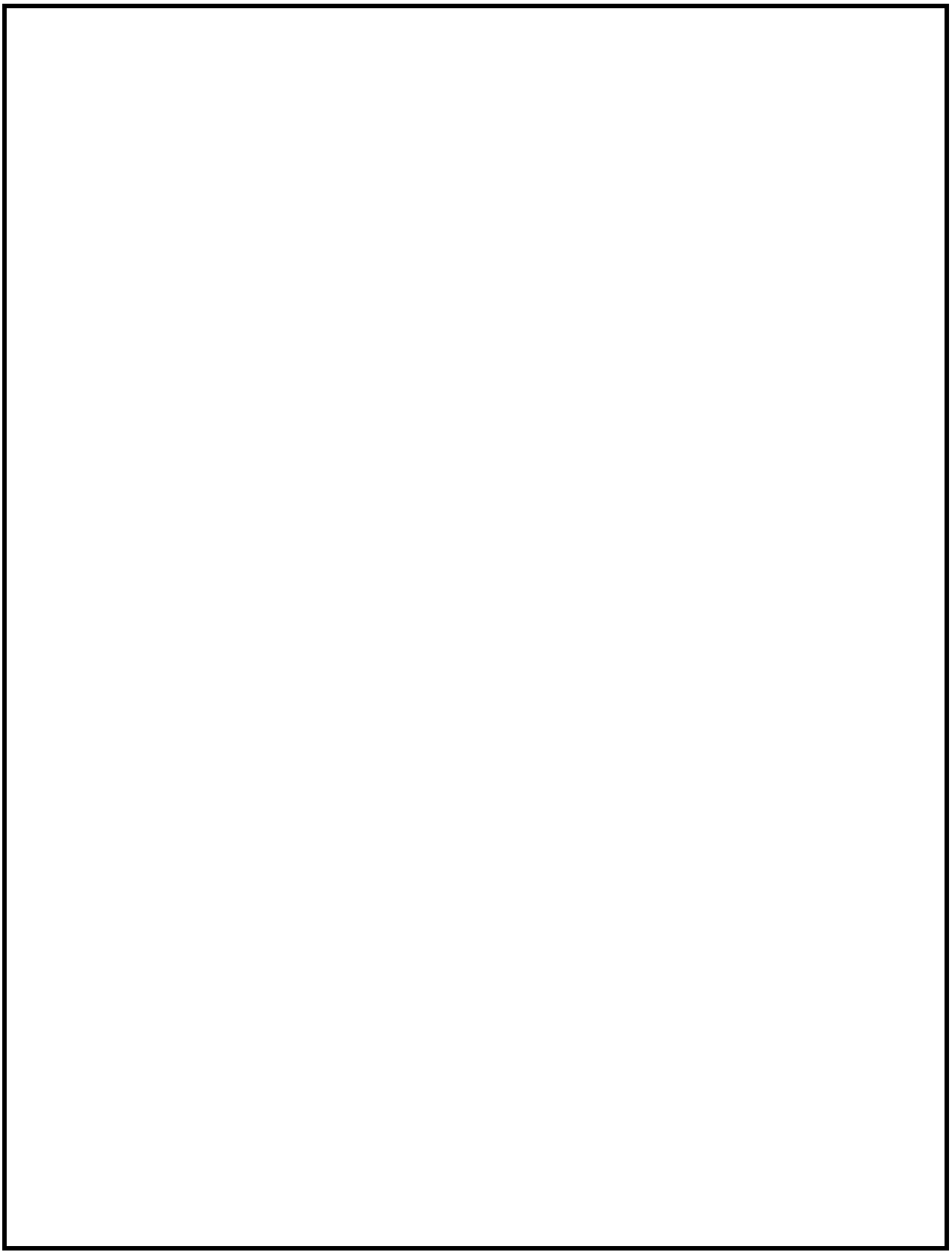
Extract 1:



Extract 2:



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.



APPENDIX II-RUBRIC FOR ESPOUSED TSPCK

RUBRIC FOR QUANTIFYING PCK –based on components for Topic Specific PCK

	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 III-INFORMATION AND CONSENT FORMS FOR PARTICIPANT PRACTICING TEACHERS

University of Witwatersrand. Education Campus, Science and Technology Division; 27 St Andrew Road; Parktown.

School Address

INFORMATION SHEET AND CONSENT - Participating project members and practicing teachers

DATE:

Dear Physical science teacher,

My name is Tarisai Mudzatsi located at Mosupatsela Secondary School and conducting research on the teaching of Physical sciences with the University of the Witwatersrand. As part of the study, a physical science teacher is exposed to a new approach of preparing and teaching science topics. This approach is called Pedagogical Content Knowledge in specific topics (TSPCK). The focus is to ensure that Science teachers can transform their understanding of concepts to versions that are accessible to learners. We would like to examine the teachers' ability to translate learnt competencies into effective classroom practices. During scheduled Chemistry lessons, each teacher needs to record his/her lessons to help us to examine the development of their pedagogical content knowledge through their involvement in a lesson study. The recording is to focus on the teacher per se, for example, the teacher may place a video recorder in her/his classroom during the entire lesson. In some cases, (logistics allowing), there maybe someone in the class taking a video of the lesson with the camera focusing only on the teacher. The teacher will also take pictures of board work done during the class. All the recordings will be viewed by the teachers and me as the researcher. The recordings will be used in improving our teaching of the topic stoichiometry. In line with ethical considerations, the recorded information will stay in a lockable place for up to five years, and then destroyed. If a need arises for us to quote a statement from the recordings a pseudonym will be used.

It is however, possible that the voices or physical appearances of learners may be caught by the recordings that will be happening. I therefore need your permission for such cases. I am aware that

consent is also needed form the parents and from the leaners themselves. Such consent forms have been prepared and I have attached samples to this email. Should a learner express discomfort with being recorded in the process, all efforts will be done to electronically block their voice or physical appearance in the recordings. All participation to the recordings will remain voluntary. The value of the recordings is to improve the way stoichiometry is taught for conceptual understanding. Also attached is the approval letter from the Gauteng Department of Education (GDE). May I kindly request that the Chairman of the School Governing Body be informed of your approval as per the conditions of the approval received from GDE.

We look forward to hear from you and wishing you a worthwhile experience in your teaching of Science and involvement in this study.

Thank you

……..
T. Mudzatsi (Researcher)

- The names and information of learners in the classes concerned will be kept confidential and safe and that the name of staff or mine or that of my school will not be revealed
- Learners do not have to answer every question and can withdraw from the study at any time.

- Leaners can ask not to be audiotaped, and/or videotaped

- All the data collected during this study will be destroyed within 3-5 years after completion of the project

Signature: _____ Date: _____

Permission for audiotaping

I agree that lessons in FET classes assigned to physical science teachers may be audiotaped YES/NO

I know that the audiotapes will be used for this project only YES/NO

Permission to be videotaped

I agree that lessons in FET classes assigned to Physical science teachers may be videotaped YES/NO

I know that the videotapes may be used for this project only YES/NO

Contactable at:

Tel: ..... Email: .....

Permission for audiotaping

I agree that I may be audiotaped during lessons of the student teacher. YES/NO

I know that the audiotapes will be used for this project only YES/NO

Permission to be videotaped

I agree I may be videotaped in class. YES/NO

I know that the videotapes 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 audiotaped, and/or videotaped
- All the data collected during this study will be destroyed within 3-5 years after completion of the project.

Signature_____ Date: _____

Contactable at:

Tel:..... Email:……

APPENDINX IV: CONSENT LETTER TO THE PRINCIPALS

University of Witwatersrand. Education Campus, Science and Technology Division; 27 St Andrew Road; Parktown.
Email: rastarisai@hotmail.com Cell: 071 980 2207

Mosupatsela Secondary School

No. 80 Sebenzisa Drive

Kagiso.

Dear Principal

INFORMATION SHEET AND CONSENT - THE SCHOOL PRINCIPAL

My name is Tarisai Mudzatsi I am a Master's degree student in Science Education in the School of Education at the University of Witwatersrand. I am conducting research on developing special knowledge for teaching Physical science called Topic Specific Pedagogical Content Knowledge (TSPCK). Your physical science teacher is participating in a professional development research programme on TSPCK using an approach called 'Lesson Study'. The programme is part of my research study. In this programme TSPCK is developed through discussions in the presence of practicing physical science teachers and experts who are teacher educators with many years of practicing experience. The topic being discussed is stoichiometry, a topic reported to be poorly understood by learners in several matric results analysis reports. I would like to observe how your physical science teacher uses the knowledge acquired in the programme in teaching the topic to one of your Grade 11 class. I will be capturing my observations by recording lessons delivered by your teacher using a video camera. I will therefore seek your permission for the video and audio-recording of the Physical sciences Grade 11 lessons in the topic stoichiometry for the teachers in your school that will participate in this study.

The recordings will be accessed only by me and my supervisor. In line with ethical considerations, the recorded information will stay in a lockable place when not analyzed, password protected for up to five years, then destroyed. If a need arises for us to quote a statement from the recordings a pseudonym will be used.

It is however, possible that the voices or physical appearances of learners may be caught by the recordings that will be happening. I therefore need your permission for such cases. I am aware that consent is also needed form the teacher, parents and the leaners themselves. Such consent forms have been prepared I attach samples to this letter. Should a learner express discomfort with being recorded in the process, all efforts will be done to electronically block their voice or physical appearance in the recordings. All participation to the recordings will remain voluntary. The ultimate value to derive from the recordings is to improve the way stoichiometry is taught for conceptual understanding. Also attached is the approval letter from the Gauteng Department of Education (GDE) giving me permission to conduct research at your school with your approval as well of that of the School Governing Body.

I trust that my request will be considered favorably, however, should you need further information please do not hesitate to contact me.

Thanking you



……..

T. Mudzatsi (Researcher)

INFORMED CONSENT

Permission to be videotaped

I agree that lessons in the physical science class of Grade 11 may be video recorded	YES/NO
I know that the videotapes will be used for this project only.	YES/NO

I understand that:

- The names and information of learners in the classes concerned will be kept confidential and safe and that the name of the teacher or mine or that of my school will not be revealed.
- Should learners feel uncomfortable or express unwillingness recordings will be stopped at any time.
- Leaners can ask not to be audiotaped, and/or videotaped
- All the data collected during this study will be destroyed within 3-5 years after completion of the project.

Signature_____ Date: _____

APPENDIX V: INFORMATION AND CONSENT LETTER FOR LEARNERS

University of Witwatersrand. Education Campus, Science and Technology Division; 27 St Andrew Road; Parktown.
Email: rastarisai@hotmail.com Cell: 071 980 2207

Mosupatsela Secondary School

No. 80 Sebenzisa Drive

Kagiso

INFORMATION SHEET LEARNERS

DATE: ……

Dear Leaner

My name is Tarisai Mudzatsi. I am a Master's Degree student in Science Education in the School of Education at the University of Witwatersrand. I am conducting research on developing special knowledge that teachers use in teaching Physical science. Your physical science teacher is participating in a professional development research programme that helps him to develop knowledge for teaching stoichiometry. The programme is part of my research study. He will be teaching your class the topic of stoichiometry in ways that makes it easy for you to understand. I would like to be able to observe the two lessons to see how your teacher delivers the lessons. While the focus in on your teacher, I however, need your permission to record the lessons using a video camera. The video helps me to capture and analyze how your teacher uses his knowledge for teaching the topic.

The recordings will be accessed only by me and my supervisor. In line with ethical considerations, the recorded information will stay in a lockable place when not analyzed, password protected for up to five years, then destroyed. If a need arises for us to quote a statement from the recordings a pseudonym will be used.

Your participation is voluntary and you have the right to refuse permission and stop participating at any time. In such cases all efforts will be done to electronically block both your voice and

physical appearance in the recordings. The ultimate value to be derived from the recordings is to improve the way stoichiometry is taught for conceptual understanding.

I am looking forward to hear from you.



……..

T. Mudzatsi (Researcher)

Informed Consent

Permission for audiotaping

I agree that I may be audiotaped during lessons of the student teacher.	YES/NO
I know that the audiotapes will be used for this project only	YES/NO

Permission to be videotaped

I agree I may be videotaped in class.	YES/NO
I know that the videotapes will be used for this project only.	YES/NO

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 can withdraw from the study at any time.
- I can ask not to be audiotaped, and/or videotaped
- All the data collected during this study will be destroyed within 3-5 years after completion of the project.

Signature_____ Date: _____

APPENDIX VI-INFORMATION AND CONSENT LETTER TO PARENTS

University of Witwatersrand. Education Campus, Science and Technology Division; 27 St Andrew Road; Parktown.

INFORMATION SHEET-PARENTS

DATE:

Dear Parent

My name is Mr Tarisai Mudzatsi; I am Physical science teacher at Mosupatsela Secondary School in Kagiso as well as a student in the School of Education at the University of the Witwatersrand. I am doing research on ways to teach Grade 11 on how to understand the topic stoichiometry and the mole concept', an integral part of understanding Physical sciences in general and chemistry in particular for studies at FET and beyond. There are efforts to teach the topic in a manner that ensures learner understanding and grasping of essential concepts. The approach we used is called Pedagogical Content Knowledge (PCK), which is considered valuable by the science education community, nationally and internationally.

The research is at a stage where I need to examine the development of PCK in a group of practicing teachers, evaluate the effectiveness of teaching by our teacher who makes up the lesson study group. During this time practicing teachers are assigned to teach various classes in the Senior/FET phase. I would like to use this opportunity to examine the quality of their pedagogical content knowledge as they teach. In order to do this, the teacher is required to video record her/his lessons. A video recorder will be placed in a position where it can record the teacher as he/she conducts the lessons on stoichiometry. While the focus of the recording is on the teacher, it is possible that the voice and possibly the physical appearance of your child/children in the class would be captured as well. I therefore need your permission for such cases. The recordings, in alignment to humanities ethics, will not be made public. They will be used by me and the lesson study group unit as we draw academic lessons from the recordings. The recordings will be kept confidential and saved in a lockable manner (e.g. password protected e-files). Your child's name and identity will academic writing about the study. His/her individual privacy will be maintained in all published and written data resulting from the study. If a need arises that we need to quote from the recordings, a pseudonym will be assigned to the person quoted.

Your child will not be advantaged or disadvantaged in any way. S/he will be reassured that s/he can withdraw her/his permission at any time during this project without any penalty. There are no foreseeable risks in participating and your child will not be paid for this study.

All research data will be destroyed between 3-5 years after completion of the project. Please let me know if you require any further information.

Thank you very much for your help.

……

T. Mudzatsi (Researcher)

Parent's Consent Form

Kindly fill in and return the reply slip below indicating your willingness to allow your child to participate in the research project called: **Examining the development of TSPCK in stoichiometry among three practicing teachers.**

I, _____ the parent of _____

Circle one

Permission to be videotaped

I agree my child may be videotaped in class. YES/NO

I know that the videotapes will be used for this project only. YES/NO

Informed Consent

I understand that:

- My child’s name and information will be kept confidential and safe and that my name and the name of my child's school will not be revealed

- He/she does not have to answer every question and can withdraw from the study at any time.

- he/she can ask not to be audiotaped and/or videotaped

- All the data collected during this study will be destroyed within 3-5 years after completion of the project.

Signature_____ Date: _____

Contactable at:

Tel: ..... **Email .....**

APPENDIX VII- GDE APPROVAL LETTER

GAUTENG PROVINCE
Department: Education
REPUBLIC OF SOUTH AFRICA

For administrative use:
Reference no: D2016 / 231
enquiries: Diane Buntting 011 843 6503

GDE RESEARCH APPROVAL LETTER

Date:	**21 August 2015**
Validity of Research Approval:	**21 August 2015 to 2 October 2015**
Name of Researcher:	**Mudzatsi T.M.**
Address of Researcher:	**106 Citi Centre; 5th Avenue; Springs; 1559**
Telephone / Fax Number/s:	**071 980 2207**
Email address:	**rastarisai@hotmail.com**
Research Topic:	**Examining the development of Topic Specific PCK in Stoichiometry of three practising teachers through a lesson study.**
Number and type of schools:	**THREE Secondary Schools**
District/s/HO	**Gauteng West and Johannesburg North**

Re: Approval in Respect of Request to Conduct Research

This letter serves to indicate that approval is hereby granted to the above-mentioned researcher to proceed with research in respect of the study indicated above. The onus rests with the researcher to negotiate appropriate and relevant time schedules with the school/s and/or offices involved. A separate copy of this letter must be presented to the Principal, SGB and the relevant District/Head Office Senior Manager confirming that permission has been granted for the research to be conducted. However participation is VOLUNTARY.

The following conditions apply to GDE research. The researcher has agreed to and may proceed with the above study subject to the conditions listed below being met. Approval may be withdrawn should any of the conditions listed below be flouted:

CONDITIONS FOR CONDUCTING RESEARCH IN GDE

1. The District/Head Office Senior Manager/s concerned must be presented with a copy of this letter;
2. A copy of this letter must be forwarded to the school principal and the chairperson of the School Governing Body (SGB);

Makhado 2015/08/24

1

Making education a societal priority

Office of the Director: Knowledge Management and Research
9th Floor, 111 Commissioner Street, Johannesburg, 2001
P.O. Box 7710, Johannesburg, 2000 Tel: (011) 355 0506
Email: David.Makhado@gauteng.gov.za
Website: www.education.gpg.gov.za

APPENDIX VIII-
HUMAN SCIENCES RESEARCH COUNCIL APPROVAL LETTER

Wits School of Education
27 St Andrews Road, Parktown, Johannesburg, 2193 Private Bag 3, Wits 2050, South Africa. Tel: +27 11 717-3064 Fax: +27 11 717-3100 E-mail: enquiries@educ.wits.ac.za Website: www.wits.ac.za

07 September 2015
Student Number: 859057
Protocol Number: 2015ECE039M

Dear Tarisai Mudzatsi

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 PCK in stoichiometry of three practicing teachers through a lesson study'.

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,

M Mabetha

Wits School of Education
011 717-3416

cc Supervisor: Dr. Elizabeth Mavhunga

APPENDIX IX:

Lesson plan on the mole concept

Physical science: Grade 11

Context: Grade 11 Revision Lesson planned for Lesson	**Periods:** Double period – 100 minutes

	Purpose of lesson
To revise the mole concept and show the relationships between mass, volume of gases and the number of particles in the amount of a substance.	
	Big Idea
The mole is the SI unit for amount of substance that is used to help chemists count elementary particles that make up a substance and provides a means to connect the macroscopic views of matter such as mass and volume (of gases) to the submicroscopic view and the number of elementary particles.	

Process skills, embedded in the assessment standards you have chosen. (Tick)			
✓	Observing and comparing		Hypothesizing
✓	Measuring		Planning science investigations
✓	Recording information		Conducting investigations
	Sorting and classifying		Communicating science information
	Interpreting information	✓	Calculations
	Predicting		

Conceptual links to previous and future lessons/learning

Previous	Future
• All matter is made up of particles (atoms, molecules and ions) and different substances are made up of different atoms. • The different types of atoms that make up matter have different relative atomic masses because the different types of atoms have a different number of protons and neutrons in their nucleus.	• Molar concentration is the amount of solute per unit volume in a solution. • In reaction stoichiometry the mass or volume of gases is used to determine the amount of substance in order to use molar ratios in balanced chemical equations to determine the mass or volume of product formed / reactants used in stoichiometric calculations.

Core knowledge

- The amount of substance is one of the seven fundamental quantities measured in science. The symbol n is used to represent the quantity amount of substance and the mole is the SI unit for the amount of substance.
- In chemistry when we refer to the amount of substance we are referring to a measurement of the size of a sample in terms of the number of elementary particles in the sample. Amount of substance does not refer to the mass of the sample, or the volume of a sample.
- The same amount of any substance has different masses because they are made up of different kinds of atoms.
- The mass of one mole of any substance has a mass that is equivalent to its relative atomic/molecular/formula mass and this mass is called the molar mass. The molar mass of any substance can be determined by using the relative atomic masses on the period table due to the equivalence of the mass of one elementary particle (measured in atomic mass units) and the mass of one mole of the substance measured in grams per mole.
- One male of any gas occupies a volume of 22,4 dm^3 at standard temperature and pressure. Standard temperature is 0°C and standard pressure is 101,3 kPa. If the temperature or pressure changes the volume occupied by the gas also changes. Molar volume only applies to gases.
- One mole of any substance contains Avogadro's number of particles and is the number of particles contained in 12 grams of carbon. Avogadro's number is a huge number of particles and is given as 6,02 x 10^{23} particles. This value has been determined experimentally and the exact number of particles is unknown, but we know it represents a constant number of particles.
- Avogadro's number allows us to count (although not the exact number) the number of elementary particles in a given mass of a substance, or the given volume of a gas.
- If we know the mass of a substance, or the volume of a gas we can determine the amount of substance and the number of particles. These relationships are expressed mathematically.

Activities

Duration	Teacher activities	Learner activities	Assessment (what, when and how)	Resources (LTSM)
Introduction **5 minutes**	1. Begin the lesson by giving the overall purpose or objective of the lesson. 2. Start off by asking learners what they understand when you use the term amount? Give an example – e.g. 'What do you think of when I say I have an amount of oranges?' Keep the question open-ended to generate from learners' own experience, do not restrict responses by	Learners generate responses relating to their understanding of amount. Possible responses could be • A certain mass of oranges • A certain number of oranges • A certain volume of oranges	Informal: Based on learner responses you can gage their understanding of the term 'amount' and work towards a shared understanding of 'amount of substance' to be used for teaching stoichiometry.	
Activity 1 Developing an understanding of the term amount **35 minutes**	1. Introduce the activity by stating that you want to find the mass of a spoonful of different substances. Emphasize that you are going to be taking the same amount (i.e. a spoonful) of each substance. 2. Ask the learners to predict if they think the mass for each substance will be the same. 3. Direct learners to take a spoonful (the same amount) of Sulphur, iron, water and sodium chloride and find the mass by placing a spoonful of substance on the digital scale.	Learners predict if the mass of a spoonful of each of the substances will be the same. Learners conduct the observation by taking a spoonful of each of		Organization: Ensure each group has enough of each substance to get about two spoonful of substance. Six spatulas or plastic teaspoons Sulphur power, iron filings, sodium chloride and bottle of water for each group. Six small electronic scales. Six watch glasses and six small beakers.

	Emphasize that they need to be accurate and get the same amount. 4. Get feedback from learners about their observations. Ask if the mass of a spoonful of each substance was the same. 5. Ask learners to explain why mass of the same amount, a spoonful, of each substance was different.	the five substances and finding the mass. Learners record their observations. Learners conduct the observation by taking a spoonful of each of the five substances and finding the mass. Learners report their observations. Learners engage with the questions and try explaining their observations.	Informal assessment. Based on learner responses you will be able to gage their understanding of atomic structure.	Paper towels to clean spoons and watch glass each time they find the mass of the next substance.

Duration	Teacher activities	Learner activities	Assessment (what, when and how)	Resources (LTSM)
Activity 1 (cont.) Developing an understanding of the term amount.	6. Ask learners why the different atoms that make up substances have different masses? Ask the learners why, when they took the same mass, they did not have the same amount? 7. Give learners microscopic models of particles of six substances. Ask them to look at the models Emphasize that the model only indicates the protons and neutrons in the atoms. Tell learners protons are in red and neutrons in blue. Reinforce that the atomic mass represent the total number of protons and neutrons in nucleus. Ask learners to determine the number of protons and neutrons in the particles. 8. Explain that due to the difference of atoms which make up substances, which have different masses, chemists need a way to measure the amount of substance. Define the term	Aim to draw on their previous knowledge about atomic structure, that different elements are composed of different atoms, compounds are made up of different atoms, that different atoms have different masses because they have different numbers of protons and neutrons in their nucleus. Different atoms have different relative atomic masses. Learners count the number of protons and neutrons in particles and record these next to the mass of the substances.	Formal assessment in tests and exams – definition of amount of substance, definition of mole as SI unit for amount of substance, Avogadro's number of particles in one mole.	Cut-out models of the substances used in the first part of the activity. Atom of Sulphur, atom of iron, molecule of water, formula unit of sodium chloride. Overhead projector and transparency with definition of amount of substance, its unit the mole.

	amount of substance; indicate that it is one of the seven fundamental quantities in science; the SI unit is the mole, and that the amount of substance is related to the number of particles in 12 grams of carbon, this number of particles is 6, 02 x 10^{23}, called Avogadro's number. 9. Write the number out to help learners get a sense of its magnitude. Emphasize that it has been determined experimentally – exact number not known, but that it is a constant number.	Learners pay attention to this information input session of the activity. Learners write out the number.		

Duration	Teacher activities	Learner activities	Assessment (what, when and how)	Resources (LTSM)
Activity 1 (cont.) Developing an understanding of the term amount	11. Use transparency to introduce / revise how to find the amount of substance from the mass. Tell the learners to calculate the amount of each substance from the mass of the spoonful and from the equal masses examples. 12. Get feedback from learners and ask if the amounts were the same.	Learners calculate the amount of substance using the relationship n = m/M Learners respond that the amounts calculated are different.	Formal assessment. Relationship between amount of substance and mass. Calculations involving the formula n = m / M.	Transparency with the amount of substance and mass relationship.
Activity 2 The analogy of the mole as a counting unit such as a dozen **25 minutes**	13. Introduce next activity as way for learner to understand how amount of substance as a quantity can be used to help count the number of particles. Introduce the notion of a counting unit like a dozen. Ask learners what number a dozen represents. Give examples e.g. two dozen, half dozen bread rolls. 14. Conduct a demonstration by finding the mass of a dozen five cent pieces and a dozen ten cent pieces. Emphasize that banks use this method of find the mass of coins to determine number of coins. 15. Hand out an envelope to each	Learners respond – a dozen represents twelve, two dozen represent twenty four, half dozen represents six. Learners record the mass of a dozen five cent coins and a dozen		Digital scale, a dozen five cent pieces, a dozen ten cent pieces. Six envelopes with multiples of a dozen (e.g. two dozen, three dozen, three and a half dozen, three and two quarter dozen, four dozen, four and a quarter dozen) in envelopes with the mass of the of the coins written on the envelopes.

	group with different amounts of either five cents or ten cents coins with the mass written on each envelope. Asks groups to work out how many dozen coins in each envelope. 16. Ask groups for feedback on how they determined how many dozen coins in each envelope. 17. Ask groups to work put the number of coins in each envelope. 18. Ask groups for feedback about how they determined the number of coins in each envelope.	ten cent coins. Groups work out from the mass how many dozen coins in each envelope. Group member gives feedback – they divided the mass of either five cent coins or ten cent coins in the envelope by the mass of a dozen five cent or ten cent coins. Groups work out the number of coins in each envelope from how many dozen coins they worked out in the envelope. Group member gives feedback – they determined the number of coins by multiplying the number of dozen coins by twelve.		

Duration	Teacher activities	Learner activities	Assessment (what, when and how)	Resources (LTSM)
Activity 2 (cont.) The analogy of the mole as a counting unit such as a dozen	19. Make the link between the dozen as a counting unit and Avogadro's number as a counting unit for use in chemistry. Emphasize that a mole contains Avogadro's number of particles, represents a large number of particles that has been determined experimentally. Emphasize exact number not known because it is so huge unlike a dozen which contains twelve items. 20. As a demonstration measure out 0.1 mole of the elemental substances used in Activity 1 (Sulphur and iron). Refer learners to the periodic table and relative atomic masses. Ask learners what they notice about the mass of 0.1 mole and the relative atomic masses of these elements. 21. Before measuring 0.1 moles of the compounds water and sodium chloride ask learners to work out from the periodic table the relative molecular mass/relative formula mass of water and sodium chloride. 22. Continue demonstration and measure mass of 0.1 mole of water and 0.1 mole of sodium	Learners refer to the periodic table and make link between the mass of 0.1 moles of the elements and the relative atomic mass of the elements. (e.g. 0.1 mole of Sulphur has mass of 3.2 g and relative atomic mass is 32 amu; mass of 0.1 mole iron has mass of 5, 6 g and relative atomic mass is 56 amu. Learners work out the relative molecular mass of the compounds by adding up the relative atomic masses of the atoms that make up the compounds (water – 18 amu, sodium chloride – 58.5 amu). Learners make link between mass of 0.1 mole of compound and relative formula/molecular mass of compounds.	Informal assessment: gage if learners can use the periodic table to determine relative atomic mass of metallic elements.	Digital scale. Five small samples bottles/measuring cylinders. Sulphur, iron, zinc. Water, sodium chloride. Preparation: Have the samples measured out beforehand so that these can just be added to the sample bottles or measuring cylinders and topped up if necessary.

	chloride. Ask learners what they notice about the mass of 0.1 moles of the compounds and the relative molecular/formula mass they calculated from the periodic table. 23. Use transparency to introduce / revise how to find number of particles from amount. Ask groups to calculate number of particles for 0, 1 mole of substance. Assign substances to groups to calculate number of particles. 24. Get feedback from learners and ask if the number of particles were the same.	Learners calculate the number of particles using the relationship $n = N/N_A$ Learners respond that the number of particles for each substance is the same.	Informal assessment: gage if learners can use the periodic table to determine relative molecular mass of molecules and relative formula mass of ionic compounds.	Transparency with the number of particles relationship to amount of substance. (Overlay transparency from amount of substance and mass relationship)

Duration	Teacher activities	Learner activities	Assessment (what, when and how)	Resources (LTSM)
Activity 2 (cont.) The analogy of the mole as a counting unit such as a dozen	25. Consolidate activity by emphasizing that in each case you have the same amount of substance and the same number of elementary units. Relate the amount of substance to the mass of substance through molar mass and amount of substance to number of particles.			
Activity 3 Molar volume of gases **15 minutes**	26. Introduce this activity by showing pervious samples and ask learners if they have the same volume, if not, why not. Emphasize that for solids and liquids the same amount of substance does not have the same volume. 27. Explain the electrolysis of water using transparency. Highlight the volumes of gases to learners and ask if the same amount of gas has been formed. Link volume of gases to number of gas molecules, emphasize that no matter how many atoms in a gas molecule, the gas same number of gas particles take up the same volume. Link volume of gases to balanced chemical equation. 28. Use photographs of collection of hydrogen gas of reaction of	Learners respond – volumes not equal, atoms of compounds have different sizes take up different amounts of space. Learners respond – twice as much hydrogen gas has been formed than oxygen gas.	Informal: gage if learners have misconception that molar volume applies to all phases of matter.	Transparency of electrolysis of water with submicroscopic particles. Photographs of collection of hydrogen from reaction of zinc and calcium with hydrochloric acid.

	zinc and calcium with hydrochloric acid. Ask learners to read off the volume, what they can say about the amount of gas formed in each case. 29. Define molar volume of gases at standard temperature and pressure, that the same amount of any gas at the same temperature and pressure has the same volume. 30. Use transparency to introduce / revise how to find amount of gas from volume. Ask groups to find the amount of gas form the volume of gas in photographs.	Learners respond – volumes are the same, the amount of gas formed is the same in each case. Learners calculate the number of particles using the relationship $n = V/V_m$		Transparency with the volume of gas relationship to amount of substance. (Overlay transparency from amount of substance, mass and number of particles relationship)

Duration	Teacher activities	Learner activities	Assessment (what, when and how)	Resources (LTSM)
Activity 3 (cont.) Molar volume of gases	31. Get feedback from learners and ask if the amounts of gas were the same. 32. Consolidate activity using transparencies to explain how the mass of one mole of substances and volume of one mole of a gaseous substance are related to the sub-microscopic particles and relative formula/molecular/atomic mass.	Learners respond that the amount of gas is the same.		Transparency showing macroscopic and submicroscopic representation for mass of substance and volume of gases. Transparency summarizing key points.
Activity 4 Ways of finding the amount of substance **15 minuets**	33. Begin activity by explaining that the amount of substance can be calculated in different ways. 34. Use transparency with overlays to show all the relationships used before relating to mass and volume of gases to amount of substance and amount of substance and number of particles. Emphasize the mathematical relationships and proportionality constants of molar mass, molar volume and Avogadro's number. 35. Hand out envelopes with work cards and problem. Facilitate problem-solving by moving to different groups. 36. Feedback – go through the	Practice – in groups learners solve problems on work card. Members explain how they calculated the amount, volume of gas and number of molecules.	Formal: Use of mathematical relationships in solving stoichiometric problems.	Overlay transparency of all the mathematical relationships. Work cards with problems and transparency with answers.

	problems by asking member of different groups how they determined the amount, volume and number of particles. Use transparency			
Conclusion **5 minuets**	37. Consolidate lesson by reminding learners that chemists use amount of substance, measured in moles to work with substances due to relationship between amount and mass and volume. 38. Show equal volumes, equal masses, equal amounts of elements to emphasize this.			Test tubes with equal volumes of three elements, equal masses of elements and one mole of elements.

Reflection