The Impact of a Learning Study on the Practice of Experienced Physical Sciences Teachers Topic-Specific PCK in Stoichiometry

Stephen Andrew Malcolm

Thesis Presented for the Degree

DOCTOR OF PHILOSOPHY

in the WITS School of Education, Faculty of Humanities

UNIVERSITY OF THE WITWATERSRAND

February 2018

Copyright Notice
The copyright of this thesis 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).

Abstract

The topic of stoichiometry, which deals with the quantitative aspects of chemical reactions, is considered difficult to teach. Students' poor performance in the topic is also well documented in the literature. In the South African context, students' poor performance in final exit examinations, particularly on the mole, have sparked concerns over the teaching and learning of the topic, which has, in turn, highlighted the need for professional development. This thesis reports on a study conducted to determine the potential of a Learning Study as a professional development activity to develop teachers' topic-specific pedagogical content knowledge in the mole. The study was conducted using a mixed methods research methodology in two distinct phases. In the first phase, the quality of experienced teachers' topic-specific PCK was determined using instruments to measure teachers' TSPCK and content knowledge. Responses to the instrument were used to determine the quality of teachers' teaching approaches when teaching stoichiometry. This phase of the study highlighted that most teachers teach stoichiometry algorithmically. These results were used to inform the second phase of the study, particularly the focus of the professional development activity. During the second phase of the study, a Professional Learning Community was formed with three teachers selected from those who had completed the instruments in the first phase of the study. These teachers were enrolled in a post-graduate program, with the Professional Learning Community forming part of their own research component. Together with their supervisors as experts, we planned a lesson on the mole, explicitly using the construct of TSPCK in a Learning Study. During the Learning Study, the lesson was critically discussed and improved on over three cycles. These discussions formed the basis of determining the development of teachers' TSPCK. The study found that the critical engagement of the lessons resulted in an improvement of the teachers' TSPCK in the topic of stoichiometry. The impact of the Learning Study, in terms of the collective topic-specific PCK evident in a Professional Learning Community being enacted in the teaching practices of the teachers in the Learning Study highlighted that they delivered significantly better lessons than a comparison group that did not work together collaboratively. Participation in a Learning Study with the explicit inclusion of TSPCK not only develops teachers' TSPCK but has a significant impact on the lessons delivered by the teachers working collaboratively. The study also contributes to the understanding of TSPCK enactment, and provides empirical

evidence in terms of the emerging patterns during TSPCK enactment that supports the consensus model of teacher knowledge.

Key words: **Stoichiometry, Topic-specific Pedagogical Content Knowledge, Learning Study**

Dedication

To Edith Joan Malcolm

(27 June 1946 – 1 July 2012)

In loving memory of my mother, Edith: for instilling in me the passion of reading which began my educational journey and the sacrifices made to keep me on the path of learning. It saddens me that you could not be here for the end of this journey.

Declaration

I declare that that this thesis is my own unaided work and has not been copied from another source. It is being submitted for the degree of Doctor of Philosophy in the University of the Witwatersrand, Johannesburg.

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

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

Student number: 89 07 001 A

Stephen Andrew Malcolm

_____

Date: 19 / 01 / 2018

Acknowledgements

Embarking on this journey would not have been possible without the support of a myriad of people. I would like to therefore thank everyone who has contributed to this five-year project, beginning with my M.Sc research in which instruments were designed to measure teachers' TSPCK in stoichiometry.

Firstly, I would like to express my gratitude to my two co-supervisors, Prof. Elizabeth Mavhunga and Prof. Marissa Rollnick. Thank you both for your continued support, guidance, encouragement and expertise that contributed to reaching finality, firstly with my M.Sc research, and in taking this research to the next level.

Prof. Elizabeth Mavhunga, thank you for the critique and valuable comments that helped me to clarify my thinking and arguments. You guidance during analysing and interpreting the statistical data was invaluable. Your suggestions and comments were always helpful and meaningful. Thank you for the teaching opportunities you provided in which to implement aspects of TSPCK in stoichiometry and the many times you allowed me to discuss aspects of TSPCK with you. It was an honour to take the construct you developed for your PhD and implement it, not only in teaching prospective teachers, but as a framework for my own research.

Prof. Marissa Rollnick, thank you for always assisting when needed, guiding my thinking and pointing me to the relevant literature. Thank you for organising the various workshops that assisted in the data analysis. Your encouragement and patience during the writing process always lifted my spirits when I felt overwhelmed by the process. Thank you for your support during this process that allowed me to present aspects of my research at NARST conferences (2016 – 2017), SAARMSTE conferences (2014 – 2018), SAARMSTE Research Schools (2015 – 2017) and the ESERA conference (2017). These opportunities helped contribute to refining aspects of my research. Thank you for encouraging me to apply for the ESERA Early Career Travel grant and ESERA Research School in the Czech Republic. Thank you for your generosity and for indulging me during the data collection. Truly it has been my honour and privilege to be your student.

Secondly, I would like to also thank Prof. Pernilla Nilsson for her hospitality during my visit to the University of Halmstad in Sweden. Her suggestions and guidance as a mentor during

my visit were inspirational. Thank you to the ESERA committee for providing the funding to visit Sweden that allowed me the opportunity to work with such a dedicated teacher educator and researcher.

I would also like to thank my mentors at the ESERA Research School, Prof. Mariona Espinet and Prof. Mathias Rophol for their valuable feedback and suggestions.

Thank you too Prof. John Bradley and Prof. Washington Dudu as the examiners for my M.Sc Report, that was un-published when I upgraded to do the PhD. Your comments and feedback helped to refine the instruments. Thank you Prof. Fred Lubben. You inspired me by being excited about my research and encouraging me at every conference and research school.

I am eternally grateful to Dr. John Linacre for his patience in guiding me through aspects of the Rasch Analysis with his comments through the *Winsteps* on-line support platform. To Prof. Tony Lelliot, thank you for your time and guidance. You enabled me to get started with the strenuous qualitatively analysis with using *Atlas.ti.*

I would also like to express my gratitude to Vivian Huang for undertaking the arduous process of proof reading all ten chapters of the original draft thesis.

I would also like to thank my fellow PhD students at Wits University, Nonkanyiso Vokwana and Josephat Miheso. Your words of encouragement kept me focused during the trying times of this incredible journey with its highs and lows. Our common focus as a community of practice not only provided me with tools for analysis but motivation as we shared this journey. To Dr. Rene Toerien, thank you for allowing me to bounce ideas off you while we were on this journey together. Your commitment and dedication were an inspiration to me.

Thirdly, I would like to express my gratitude to my partner, Coenraadt Moolman for his support and understanding during the many hours and late nights while I was working on this project. To all my friends and family for understanding all the times I had to turn down your invitations. I would like to specifically thank my sister, Joan Malcolm, friends Denis Hutchinson and Jason Donovan Storey for their assistance during the trying financial times of student life.

I would like to thank my students who allowed me to use the answers to stoichiometric problems as authentic responses in designing the instruments and trial aspects of the stoichiometry lessons with you. Thank you too for your willingness to learn stoichiometry

through new approaches as my own pedagogical content knowledge developed during the process. Thank you Mr. Van Biljon for your kindness and encouragement to take the opportunity to study fulltime.

Lastly, to all the teachers who willingly agreed to participate at various stages of the research process, including the design of the TSPCK instrument completed during my M.Sc research.

To the four teachers who spent so much time and energy and responded to all the items generated during the pre-piloting stage. Your contribution was invaluable in generating the semi-closed responses. Thank you for the many hours set aside in your busy schedules. To the eight teachers, whom I proudly call friends and colleagues, who piloted the instruments, thank you for your time and comments. Your input helped me to rectify errors, especially on the CK Instrument. To the thirty one teachers who completed the instruments during the validation stage, thank you so much for your willingness and time. Thank you to those of you who got your friends involved too. To the nine of you, whose responses never reached me due to the postal strike in 2013, I apologise that your efforts were in vain. However, I am grateful for the time you spent completing the instruments.

To the three teachers of the comparison group, who allowed me access to their classrooms to observe them teaching – thank you! I know that it is difficult to invite a stranger into your classroom. But you willingly allowed me in with my video camera for two weeks.

I am also grateful to the three teachers who came together to form the Professional Learning Community. Learning Study is an arduous undertaking. Thank you for the long hours during the meetings. Thank you for the privilege of allowing me to work with you to develop a lesson on the mole as part of your own Masters' research with your respective supervisors. Thank you for your willingness and openness to share your ideas, your experience and your practice with me. Thank you for allowing me the opportunity to see you working with your students. This study would not have been possible without you. A special thank you to your students, who volunteered their Saturday mornings to attend the lesson.

Last, but not least, thank you to the experts in Chemistry education who willingly agreed to be co-opted into the PLC as part of your role in supervising the Learning Study teachers' research projects. Your experience and wisdom were invaluable in improving the lesson on the mole.

This thesis is a culmination of my commitment and dedication to the ideal of quality education for all. It is my hope that this labour of love to that ideal can, in some small way, impact positively on the way that teachers teach the topic of stoichiometry. It is also my hope that teachers can see the value of collaboration, the benefits of sharing their practice and learning from each other to deliver better education for their students. To quote the great Nelson Mandela: “Education is the great engine of personal development. It is through education that the daughter of a peasant can become a doctor, that the son of a mine worker can become the head of a mine”. Teachers therefore play an important role in the personal development of their students and effective teachers strive towards finding ways to improve their teaching for the leaders of tomorrow.

The research was made possible by the National Research Foundation and the Marang Centre for Maths and Science Education who provided the funding that allowed me to become a full-time PhD fellow and complete this study.

Contents

Chapter 1: Introduction and Orientation to the Study 1

1.1. Preamble 1

1.2. The Topic-Specific Context of the Study: Stoichiometry 2

1.3. Problem Statement 4

1.4. Purpose of the Study 5

1.5. Rationale for the Study 6

1.6. Research Questions 8

1.7. The Researcher and Positionality 10

1.8. Structure of the Thesis 11

Chapter 2: Literature Review and Theoretical Framework 13

2.1. Overview 13

2.2. Teacher Knowledge 14

2.3. Capturing and Measuring Pedagogical Content Knowledge 19

2.4. Effective Teaching 26

2.5. Teaching Stoichiometry and Student Alternative Conceptions in Stoichiometry 33

2.6. Theoretical Framework 41

2.7. Summary 51

Chapter 3: Research Methodology 53

3.1. Introduction 53

3.2. Research Paradigm 55

3.3. Research Design: Mixed Methods 56

3.4. Research Strategy: Case Study 60

3.5. Participants 62

3.6. Treatment 69

3.7. Data Collection and Data Analysis 70

3.8. Validity and Trustworthiness 99

3.9. Ethical Issues 102

3.10. Reflexivity 103

3.11. Reflections 106

Chapter 4: The Quality of Experienced Teachers' TSPCK and CK as Measured by the Developed Instruments 107

4.1. Introduction 107

4.2. Scoring the TSPCK Instruments 109

4.3. General performance of the Teachers in the TSPCK Instrument 111

4.4. Performance in the Content Knowledge Instrument 131

4.4. Relationship between TSPCK Scores and CK Scores 136

4.5 Teachers' Conceptions of the Mole 141

4.6. Conceptualisation of the Mole and TSPCK Responses: Teacher Profiles 144

4.7. Summary 151

Chapter 5: The Learning Study as a Professional Development Activity 153

5.1. Introduction 153

5.2. Forming the Professional Learning Community 154

5.3. The Goal-directed Action of the Professional Learning Community 166

5.4. Summary 185

Chapter 6: The Impact of the Learning Study on the Quality of Teachers' Measured TSPCK 187

6.1. Introduction 188

6.2. Teachers' Change in Score on the TSPCK Instrument 188

6.3. Comparison of Pre-Test and Post-Test Scores Using Rasch Measurements 189

6.4. The Focus and Participation in the Professional Learning Community 199

6.5. Qualitative Analysis of Changes in Scores – The Story of Three Teachers 209

6.6. Teacher Learning and Interactions in the PLC Meetings 227

6.7. Summary 233

Chapter 7: The Quality of Teachers' Enacted TSPCK in the Classroom 235

7.1. Introduction 235

7.2. Lesson Elements and TSPCK Episodes in the Lessons 237

7.3. Identifying and Scoring the TSPCK Episodes 240

7.4. Overview Analysis of the Number and Quality of TSPCK Episodes 245

7.5. Statistical Analysis of TSPCK Episodes in the Lesson Elements 264

7.6. Summary 267

Chapter 8: Discussion and Implications 269

8.1. Introduction 269

8.2. Overview of the Study 270

8.3. Discussion of Findings 273

8.4. Contribution to Understanding of Teacher Knowledge 286

8.5. Recommendations 298

8.6. Limitations of the Study 301

8.7. Personal Reflections 302

References 306

Appendices 327

List of Figures

Page no.

Figure 2.1: The amount of substance in relation to the quantities mass, volume and number of elementary entities **40**

Figure 2.2: The TPK&S model including PCK derived at the PCK Summit in Colorado **43**

Figure 2.3: Model of Topic-specific PCK **45**

Figure 2.4: Model of teacher thought and action **47**

Figure 2.5: Reworked TPK&S Model including TSPCK and teaching model for teaching stoichiometry **50**

Figure 3.1: Summary of multiphase mixed methods design for this study **57**

Figure 3.2: Summary of Phase I exploratory sequential design data collection for the Study **71**

Figure 3.3: Extract for Excel Spread Sheet Capturing Responses to TSPCK Items **76**

Figure 3.4: Summary of Phase II Convergent Parallel Design Data Collection for the Study **78**

Figure 3.5: Integration and triangulation of data collection methods for convergent parallel design of Phase II **84**

Figure 3.6: Extracts from coding manual to illustrate the levels of coding and grouping of codes into coding families **88**

Figure 3.7: Extract from *Atlas.ti* to illustrate the coding process of the transcriptions of the PLC meetings **90**

Figure 3.8: An example of a TSPCK map developed from a summarised TSPCK episode from the pilot lesson of the Learning Study **94**

Figure 3.9: Summary of how lesson segments with interacting TSPCK components were assigned to teaching contexts **98**

Page no.

Figure 4.1: An extract from the TSPCK rubric modified for this study **110**

Figure 4.2: Teachers scores across the five components of TSPCK **112**

Figure 4.3: Bar graph of the different types of representation used by teachers in their conceptual teaching strategy **116**

Figure 4.4: Examples of symbolic representations used to determine limiting reagents **117**

Figure 4.5: Examples of other representations used by teachers to explain limiting reagents **119**

Figure 4.6: Christine's and Janet's responses to Category E item and photographs of actual practice to illustrate the limitations of only using one method to measure PCK **122**

Figure 4.7: Hendrick's response to Category E item and photographs of actual practice to illustrate the limitations of only using one method to measure PCK **123**

Figure 4.8: Bubble plot of fit indices for item difficulty and person ability for TSPCK generated through *Winsteps Ministeps* (N= 31) **126**

Figure 4.9: Sample of a score sheet used to determine the total score for the Content Knowledge instrument **132**

Figure 4.10: Relationship between CK and TSPCK of teachers in stoichiometry **138**

Figure 4.11: Examples of responses indicating respondents' conception of the mole **142**

Figure 4.12: Pie chart of teachers' conception of the mole (N = 31) **143**

Figure 4.13: Segmentation maps and central mean graphs from cluster analysis **145**

Figure 5.1: Macroscopic and sub microscopic representations of concentration used during the presentation describing a teaching episode **171**

Figure 5.2: Steps in a Learning Study using a CoRe as a planning tool **174**

Figure 5.3: The adapted CoRe used to plan the lesson of the Learning Study **176**

Page no.

Figure 5.4: From the planning meeting the written out aspects of what is difficult to teach are captured in the adapted CoRe **179**

Figure 5.5: Extract from the lesson plan drawn up from the discussions of the conceptual teaching strategies indicating teacher activities, learning activities and resources **180**

Figure 5.6: The agenda for the discussion meeting held for the piloting of the lesson on the mole **181**

Figure 5.7: A collage of pictures from the four cycles of the lesson on the mole **184**

Figure 6.1: Rasch analysis data from original sample of teachers (N=31) and the stacked sample with post-test results from three teachers in the Learning Study **192**

Figure 6.2: Rasch analysis data from original sample of teachers (N=31) and the stacked sample (N=34) with post-test results showing item ranking order **193**

Figure 6.3: Rasch analysis data from original sample of teachers (N=31) and the stacked sample (N=34) showing Person measure summary statistics **194**

Figure 6.4: Rasch analysis data from original sample of teachers (N=31) and the stacked sample (N=34) showing Item measure summary **195**

Figure 6.5: Person-item map with the post-test scores for the three teachers participating in the Learning Study included as new persons **197**

Figure 6.6: Collage of word cloud of common terms used in meetings and photographs showing members of the PLC engaging in the various activities of the Learning Study cycles **201**

Figure 6.7: Line graph of talk units in each meeting of the Learning Study **202**

Figure 6.8: Graphs of TPK&S units and TSPCK units from double and triple coding of the specialised knowledge talk units **204**

Figure 6.9: The generation of a cross tabulation of all codes in *Atlas.ti* from the transcripts of the meeting of the PLC **206**

Page no.

Figure 6.10: Bar graph to show the participation of each team member of the PLC in terms of talk units **207**

Figure 6.11: Percentage participation in discussion meetings for Cycle 1, Cycle 2 and Cycle 3 of the Learning Study **208**

Figure 6.12: Extracts from Tendani's beliefs and self-efficacy questionnaire used to develop context for vignette **211**

Figure 6.13: Extracts from Sizwe's pre-t and post-test to show his improvement in the item CSA **213**

Figure 6.14: Tendani's responses the LPK and WDT items in the pre-test and post-test **215**

Figure 6.15: Sizwe's response to the REP item in the pre-test and post-test and extract from CoRe after the Learning Study **217**

Figure 6.16: Sipho's response to CTS item in pre-test and post-test **219**

Figure 6.17: Bar graphs of change in pre-test and post-test scores and number of TSPCK talk units in the PLC activities **228**

Figure 7.1: The TSPCK rubric with criteria for describing the quality of TSPCK episodes seen in enacted TSPCK in the classroom **244**

Figure 7.2: Total percentage of TSPCK episodes per quality category for the Learning Study group and the comparison group **249**

Figure 7.3: Enumerating TSPCK component interactions **253**

Figure 7.4: Bar graph of percentage of connections between TSPCK component pairs and total connections for the two groups of teachers **258**

Figure 7.5: Percentage connections between TSPCK components for the three teachers in the Learning Study group **259**

Figure 8.1: Summary of Phase I of Study **271**

Page no.

Figure 8.2: Summary of Phase II of the Study **272**

Figure 8.3: Person-item maps to show development in TSPCK based on performance in TSPCK Instrument **280**

Figure 8.4: Pedagogical transformation processes (Bishop & Denley, 2007)with links to lesson elements **288**

Figure 8.5: An idealised TSPCK Event Map with connections between all five TSPCK components and possible permutations to represent the quality of TSPCK **290**

Figure 8.6: Links to findings in study with the TPK&S model **296**

List of Tables

Page no.

Table 2.1: The links between the teaching model subordinates and curricular saliency **49**

Table 3.1: Table of baseline characteristics of the teachers in the intervention group and the comparison group **66**

Table 3.2: Types of questions designed for the various components of TSPCK in stoichiometry **72**

Table 3.3: Table of summary statistics for person and item reliability of TSPCK instrument **72**

Table 3.4: Table of summary statistics for person and item reliability for the CK instrument **73**

Table 3.5: Relationship between criteria for a narrative and data sources **86**

Table 3.6: Lesson elements and teacher tasks of each element used to as TSPCK Map Platforms **96**

Table 4.1: Summary of the ways in which teachers identified the learner errors **114**

Table 4.2: The ranked Rasch measure for each teacher determined through Rasch Analysis based on ordinal scores for each component of TSPCK **127**

Table 4.3: Quantification and Ranking of Grade 11 Physical Sciences teachers achievement in the CK Instrument for stoichiometry **134**

Table 4.4: Teachers' teaching strategies and conceptions of the mole **147**

Table 5.1: Schedule of goal-directed collaboration of Professional Learning Community **165**

Page no.

Table 6.1: Scores from TSPCK Instruments of the participants involved in the Learning Study **189**

Table 6.2: Person measure values from Rasch analysis of the stacked data to show gains in person ability in terms of the Rasch model **198**

Table 6.3: Output data from cluster analysis showing groupings of teachers into 3 clusters **199**

Table 7.1: TSPCK Profiles of teachers in the Learning Study group and the Comparison Group **245**

Table 7.2: A summary of TSPCK episodes in the Learning Study group and comparison group respectively **248**

Table 7.3: TSPCK Event maps for the concepts of the mole as a counting unit and molar volume for teachers in the Learning Study and comparison groups **255**

Table 7.4: Average scores of TSPCK episodes for each lesson element in the Learning Study group and the comparison group **265**

List of Acronyms

ASECA	A Secondary Education Curriculum for Adults
BPIM	*Bureau International des Poids ET Mesures*
B.Ed	Bachelor of Education
B.Sc	Bachelor of Science
CAPS	Curriculum and Assessment Policy Statement
CCI	Chemical Concepts Inventory
CI	Confidence Interval
CK	Content Knowledge
CoRe	Content Representation
cPCK	Collective Pedagogical Content Knowledge
CSA	Curricular saliency
CTS	Conceptual teaching strategy
DBE	Department of Basic Education
DHET	Department of Higher Education and Training
DoE	Department of Education
ePCK	Enacted Pedagogical Content Knowledge
LPK	Learner Prior Knowledge
MNSQ	Mean Square
M.Sc	Masters in Science
NCS	National Curriculum Statement
NGO	Non-government Organisation
PhD	Doctor of Philosophy
PaP-eR	Pedagogical and Professional-experience Repertoire
PCK	Pedagogical Content Knowledge
pPCK	Personal Pedagogical Content Knowledge
PK	Pedagogical Knowledge
PLC	Professional Learning Community

p-value	The probability value that indicates the probability for a given statistical model
r	Correlation coefficient
REP	Representations
SACHED	South African Council for Higher Education
SE	Standard Error
SI	Système Internationale or International System of measurements
SRI	Stimulated Recall Interview
TSKFT	Topic-specific Knowledge for Teaching
TSPCK	Topic-specific Pedagogical Content Knowledge
TPK&S	Teacher Professional Knowledge & Skills
TSPK	Topic Specific Professional Knowledge
UNISA	University of South Africa
WDT	What is difficult to teach
W value	A Wilcoxon test statistic which equals the sum of the ranks in one of both groups.
ZSTD	z standard distribution
Z value	A Wilcoxon test statistic which equals the sum of signed ranks divided by the square root of the sum of their squares.

List of Appendices

A1. Ethical Considerations

A2. Research Instruments

A3. Coding Manual

A4. Conceptualization of the Mole

A5. Defining the Content

A6. Framing the Big Ideas

A7. Precursors to designing the instruments

A8. Design and Validation of TSPCK Instrument

A9. The Development of the TSPCK Instrument

A10. The Development of the CK Instrument

A11. The Validity of the CK Instrument

A12. Quality of Teachers TSPCK related to Learner Prior Knowledge and Student Difficulties

A13. Quality of Teachers' TSPCK in Curricular saliency and Representations

A14. Teachers' Conception of the Mole and the Quality of Teachers' CK in Stoichiometry

A15. Teacher Profiles for Teaching Stoichiometry

A16. The Evolution of a Lesson on the Mole

A17. In-Depth Analysis of the Lessons on the Mole

A18. Developing Vignettes for Each Teacher to Describe Emerging Patterns

A19. How Participation in the Learning Study had an Impact on Classroom Enactment of TSPCK

A20. Sample of Raw Data

A21. Statistical Analysis

A22. Hermeneutic unit

CHAPTER ONE

Introduction and Orientation to the Study

This chapter begins by broadly describing what classroom teaching encapsulates and how experienced teachers develop their knowledge for teaching through experience. The chapter then broadly defines the topic of stoichiometry and outlines the difficulties encountered by learners in this topic. It introduces the study within the South African context, and, in particular, the lack of content knowledge and pedagogical content knowledge of South African teachers, based on the reported poor performance of matric learners in questions related to stoichiometry. The rationale for the study is described within this context. The chapter also provides the aims of the research and research questions that guided the study. The chapter closes with a brief description of the researcher's positionality and an outline of this thesis.

1.1. Preamble

Classroom teaching, a central process in education, includes a myriad of activities that take place in the social setting of a classroom (Doyle, 1986; Gage, 1984). In this setting, the aim of teaching is to ensure that learners comprehend the content, through a series of activities that provide opportunities for learning and, indeed, lead toward learning (Gage, 1984; Shulman, 1987). It is generally accepted that novice teachers tend to lack the necessary confidence in their teaching ability, have difficulty mastering the content and maintaining the pedagogical flow of their lessons (Gess-Newsome, 1999b; Karamustafaoğlu, 2007). How then do novice teachers move into the realm of being experienced teachers? Field and Latta (2001) pose the question: 'what counts as experience?' Is an experienced teacher someone who has mastered the content knowledge they are teaching, has built up a repertoire of teaching strategies or developed a set of concrete skills related to planning and classroom enactment?

Practicing teachers do indeed learn through experience, developing a deeper understanding of the intricacies of teaching through reflective consideration of their teaching practices (Gess-Newsome, 1999b; Loughran, Berry, & Mulhall, 2012; Loughran & Russell, 2009). Teaching is a complex process requiring the integration of practice and theory, often described as an art, which requires knowledge, skills and abilities that continually need to be developed for

quality teaching (Gage, 1984; Hassard, 2005; Loughran, 2009, 2014). Experienced teachers, who have the necessary content knowledge, general pedagogical knowledge and knowledge of learners, have the ability to blend content and pedagogy into a form of practical knowledge to help learners understand the necessary concepts of the topics they are teaching (Gudmundsdottir & Shulman, 1987; Rowan *et al.*, 2001; Shulman, 1987). Shulman (1987) defined this amalgam of content knowledge and pedagogical knowledge that is transformed by teachers into an understanding of how particular topics are organised, represented, adapted and presented for instruction to meet the diverse interests and abilities of learners as pedagogical content knowledge, or PCK. This definition encompasses a teacher's understanding of content knowledge and the enactment of this knowledge in the classroom.

Since Shulman first defined PCK he acknowledges that there were 'some weaknesses and limitations of the original formulations' (Shulman, 2015, p. 9). Researchers have focused on the concept in order to define and describe the concept and categorise the knowledge that should be included in the concept but have not been successful in establishing a precise, or universal definition (Ball, Thames, & Phelps, 2008). There therefore exists a divergence of definitions for PCK related to PCK as a form of teacher knowledge, or a skill or both (Gess-Newsome, 2015). It is generally accepted that teachers draw on this specialised knowledge when teaching (Park & Oliver, 2008; Rowan *et al.*, 2001). It is also evident that teachers' knowledge changes with time and experience, guides the teaching practice of effective teachers and can be developed through professional development opportunities (Abell, 2008; Gess-Newsome, 1999b; Shulman, 1987). With experience, teachers also gain what Shulman (1987) refers to as 'wisdom of practice'. This study aims at investigating this specialised knowledge of experienced teachers during classroom enactment. More specifically, it aims to investigate how this knowledge is developed through participation in a collaborative professional learning activity and is translated into enacted PCK in the classroom.

1.2. The Topic-Specific Context of the Study: Stoichiometry

Much of the research done on PCK has, according to Abell (2008), confirmed that teachers develop and use knowledge for teaching specific topics. This highlights the need to study teacher knowledge within topic-specific contexts. The chemistry topic stoichiometry taught at secondary school level is therefore of particular interest for this study. This topic is considered problematic since teachers find it difficult to continually improve the teaching of

the topic, and learners struggle with the topic itself (Gulacar, Overton, Bowmanc, & Fyneweverd, 2013; Huddle & Pillay, 1996). Stoichiometry deals with the quantitative aspects of chemical reactions (Kolb, 1978; Silberberg, 2006) and is an important topic in the secondary school curriculum. The topic's inclusion in the school curriculum can be linked to the importance of quantitative analysis of chemical reactions, which is essential for analytical chemistry, applied in a wide range of science disciplines, industry and medicine (Skoog, West, Holler, & Crouch, 2004). More importantly, however, is its progression in the school curriculum, since concepts in stoichiometry are needed for conceptual understanding in other chemistry topics, such as chemical equilibrium and acids and bases (Okanlawon, 2010; Potgieter, Rogan, & Howie, 2005).

Stoichiometry is therefore a fundamental topic in chemistry, not only as a tool for solving problems in topics like chemical equilibrium and acids and bases, but due to the central role of chemical analysis in other scientific fields, medicine and industry (Figueira, Coch, & Zeplca, 1988; Okanlawon, 2010; Skoog *et al.*, 2004). However, the topic is rarely taught by secondary school teachers in a way that its practical importance or relevance is made apparent to learners (Evans, Leinhardt, Karabinos, & Yaron, 2006; Figueira *et al.*, 1988). Chemistry teachers identify the 'mole concept', essential for an understanding of stoichiometry, as one of the most difficult concepts for learners to grasp, due to the mathematical application of the mole (Dierks, Weninger, & Herron, 1985; Evans, Yaron, & Leinhardt, 2008; Gulacar, Overton, & Bowman, 2013).When teaching stoichiometry, teachers therefore tend to focus on the algorithmic aspects, such as mathematical calculations, rather than developing conceptual understanding (Agung & Schwartz, 2007). To exacerbate the problem, according to Nelson (2013) surveys of educators have revealed that many teachers do not have a proper understanding of the mole concept. Due to this conceptual uncertainty, teachers are unable to develop an integrated learning approach for learners (Strömdahl, 1996). Consequently, learners find stoichiometry difficult and consider the topic both discouraging and uninteresting (Fach, de Boer, & Parchmann, 2007). The lack of clarity teachers have regarding the mole concept, their focus on an algorithmic teaching approach and learner difficulties in this topic in a South African context are outlined below.

1.3. Problem Statement

A report compiled by the Centre for Development and Enterprise (Clynick & Lee, 2004) indicated that only 12,1 per cent of Physical Science teachers in South Africa have a science specialisation with less than half of these educators having university degrees. Although there have been some improvements, Spaull (2013, p. 3) still describes the situation as 'dire and consistent' since teachers' have below-basic levels of content knowledge, especially in rural schools and previously disadvantaged schools. Prior to 1994, many South African teachers usually obtained three-year teaching diplomas. These teachers, therefore, have the equivalent content knowledge of first year physics and chemistry at university (Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008). Therefore, many practising science teachers have limited conceptual knowledge, including limited content knowledge, and lack professional confidence, perpetuating a 'cycle of mediocrity' in the classroom (Department of Basic Education & Department of Higher Education & Training, 2011a; Department of Education, 2006). To exacerbate the problem, in the *National Curriculum Statement*, or NCS, for Physical Sciences (Department of Education, 2003), stoichiometry was only covered in Grade 11. Due to ongoing challenges with the implementation of the *Revised National Curriculum*, the curriculum was reviewed and amended, with effect from 2012 (Department of Basic Education, 2011a; Taole, 2013). With the revision of the curriculum, the *Curriculum and Assessment Policy Statement*, or *CAPS*, (Department of Basic Education, 2011a) introduces the topic in Grade 10. The introduction of stoichiometry in Grade 10 could possibly expose experienced teachers, who may have previously not taught stoichiometry, to a new content area (Clynick & Lee, 2004).

South Africa has a national policy that aims to assist teachers to enhance their professional competence and performance, and recognises the need for teachers to reflectively develop their skills, content knowledge and pedagogical content knowledge (Department of Education, 2006). However, traditional approaches to professional development have been both inadequate and inappropriate to enhance professional competence and performance (Kriek & Grayson, 2009). The need for professional development to be centred around the teacher through the creation of professional learning communities, described in the rationale, has been highlighted as a vehicle to develop teachers' knowledge and practice (Department of Basic Education & Department of Higher Education & Training, 2011a).

Evidence of learners' lack of proficiency in stoichiometry in South Africa has been highlighted with the inclusion of stoichiometric calculations in the final matriculation examinations over the past few years. Stoichiometric calculations have been included in questions related to chemical equilibrium, rates of chemical reactions and electrochemistry. The national reports on learner performance in these questions (Department of Basic Education, 2011b, 2013, 2014, 2016, 2017) highlight the lack of basic understanding of stoichiometric concepts and an inability to solve stoichiometric problems. These reports also recommend that teachers spend more time teaching this topic effectively and indicate the need for professional development activities to assist teachers to teach the topic better. At a tertiary level, students tend to lack the necessary proficiency and basis for success in chemistry courses and generally perform poorly, despite stoichiometry being covered in the school curriculum (Potgieter *et al.*, 2005). One of the possible reasons for this disparity between students' lack of proficiency in stoichiometry at a tertiary level, and having been taught the content in secondary school, could be attributed to the shortage of qualified teachers (Department of Basic Education & Department of Higher Education & Training, 2011a). This study therefore focuses firstly, on the articulation of experienced teachers topic-specific PCK in stoichiometry through both measurement and portraying it in classroom enactment. Secondly, how this knowledge is developed through participation in a Professional Learning Community, in planning to teach the topic of stoichiometry, and is manifested in enacting planning in the classroom when teaching stoichiometry.

1.4. Purpose of the Study

In the South African context, the genesis of research in PCK developed from the need to address teachers' content knowledge in a meaningful way that allowed teachers to discuss aspects of their practice, while at the same time developing teachers conceptual understanding of the content (Rollnick & Mavhunga, 2015). The purpose of this study is to contribute to the understanding of the topic-specificity of PCK through the transformation of content knowledge into classroom enactment (Rollnick & Mavhunga, 2015). In the topic-specific context of stoichiometry, it aims to explore the potential of experienced teachers working collaboratively, in planning to transform content knowledge for teaching purposes as a professional learning activity and the impact on their PCK development and enactment in the classroom. In order to successfully explore both the development of PCK for the topic of stoichiometry and the impact of teachers working together collaboratively on classroom

enactment, it is necessary to establish the status of experienced practicing Physical Sciences teachers' knowledge bases in this topic. It was therefore necessary for instruments that can contribute to measuring the baseline PCK and content knowledge in this topic to be developed and validated for this study (Malcolm, 2015). This was necessary to establish the quality of PCK and content knowledge currently prevailing in a sample of experienced practising South African teachers. It is envisaged that the findings of this study will contribute to a better understanding of practising teachers' enacted topic-specific PCK, how it can be developed and how teachers use this knowledge in classroom enactment.

1.5. Rationale for the Study

The notion of PCK was conceived from the idea of reforming teaching and was first described by Shulman (1986b). It was introduced as one of the knowledge domains or categories of knowledge represented in the mind of the teacher required for effective teaching. Since the initial introduction of PCK, various models have been developed by various researchers and all have been modified in different ways from Shulman's original proposal (Kind, 2009b). Researchers have also used the construct and models in various studies to develop an understanding of teacher knowledge (Abell, 2008). Numerous PCK studies have focused on experienced teachers, since PCK develops with experience, and E. Lee and Luft (2008) argue that the best representation of PCK resides within experienced teachers. E. Lee and Luft (2008) focused on eliciting what experienced teachers considered the main elements of PCK and how teachers organised these elements.

There are however, limited studies on determining the relationship between the quality of teachers' PCK and their classroom enactment (Abell, 2008). Studies that have focused on enactment have investigated either how the quality of experienced teachers PCK is correlated to their implementation of reform-based practices such as inquiry learning (Park, Jang, Chen, & Jung, 2011), or the on-site development of PCK in which teachers invent on the spot instructional strategies in response to unexpected learner questions or comments when teaching a new topic (Chan & Yung, 2015). An understanding of the reasoning behind the decision-making and choices made by teachers in the classroom due to the quality of their PCK, can be used in pre-service teacher education to influence the development of their thinking (Rollnick & Mavhunga, 2015). Although the two studies mentioned above (Chan & Yung, 2015; Park *et al.*, 2011) were centred on specific topics, the interpretation was based

on a generic conceptualisation of PCK, rather than the implementation of planning based on the transformation of components, such as representations or instructional strategies which have been shown to be topic-specific (Aydin, Friedrichsen, Bozc, & Hanuscinb, 2014).

A topic-specific lens, therefore, has the potential for providing a more coherent, less idiosyncratic picture of the integration of knowledge components in classroom enactment (Park & Chen, 2012). As a construct, topic-specific PCK has been used to design valid and reliable instruments to measure the quality of PCK in the topics of chemical equilibrium (Mavhunga, 2012), electrochemistry (Ndlovu, 2014), electric circuits (Zimmerman, 2016) and organic chemistry (Vokwana, 2013). The construct has also been successfully used in an intervention with pre-service teachers, taught explicitly in a science methodology course, and been shown to develop and fast-track the trajectory of PCK development of these pre-service teachers (Mavhunga, 2012). Recent studies have focused on the interaction of the components of TSPCK (Mavhunga, 2015), the transfer of the pedagogical competence of transformation across chemistry topics (Mavhunga, 2016) and how TSPCK evident in planning is translated into classroom teaching, or enacted TSPCK (van der Merwe, 2018). These studies have highlighted the complexity of interactions (Mavhunga & van der Merwe, 2017) but have focused on preservice teachers rather than experienced teachers.

Within the South African context, the state of science education is of concern due to practising teachers' limited content knowledge and ineffectual teaching practices evidenced by poor performance both in local and international measures (Kriek & Grayson, 2009; Rollnick & Mavhunga, 2015). Many of the concerns related to the quality of education in South Africa can be linked to the qualifications of practising teachers due to South Africa's historical legacy (Kriek & Grayson, 2009; Rollnick & Mavhunga, 2015). In order to improve the teaching of science, practising teachers need to undergo professional development but many of the interventions sanctioned by the Department of Education are short-term, have no theoretical basis and are ineffective (Kriek & Grayson, 2009). Professional Learning Communities, convened and centred around explicit discussions of the transformation of content knowledge for particular topics, therefore offer the potential to improve teachers' conceptual understanding and understanding of learner errors (Brodie, 2011, 2014; Rollnick & Mavhunga, 2015). Developing practising teachers' topic-specific PCK through involvement in Professional Learning Communities has been described as a more sustainable and generative method for teacher development (Brodie, 2011), as it can allow teachers to

focus on classroom enactment (Department of Basic Education & Department of Higher Education & Training, 2011a). Studies conducted by Nilsson (2014) and Nilsson and Vikström (2015) have highlighted the benefits of collaboration amongst teachers working together in the collegial process of a Learning Study in both developing teachers' PCK and improving teaching practice. This study is distinctly different from the aforementioned studies in that, unlike these studies that investigated the development of generic PCK components outlined in the Magnusson, Krajcik, and Borko (1999) model, this study focuses on PCK development through the lens of the topic-specific PCK model (Mavhunga, 2012). More specifically, this study explores how the process of the Learning Study discussion with the explicit inclusion of the collective topic-specific PCK[1] of the members of a Professional Learning Community impact on the personal topic-specific PCK[2] of teachers within a Learning Study group.

The framework of topic-specific PCK and its development in practising teachers within a Professional Learning Community can therefore allow the impact of the development of teachers' topic-specific PCK on their classroom enactment to be explored (Rollnick & Mavhunga, 2015). The potential findings of this study may not only be relevant to improving the teaching and learning of a difficult topic in chemistry in South Africa, but also contribute to understanding PCK in terms of teacher knowledge, teacher thinking and classroom practice that have recently been reconceptualised by researchers in the field (Gess-Newsome, 2015; Shulman, 2015). This study therefore aims to explore the current gap in the literature related to how teachers, working collaboratively draw from the collective PCK represented in a Professional Learning Community in planning a lesson, and how this is translated into enacted topic-specific PCK[3] in the classroom.

1.6. Research Questions

The starting point of this study is based on the problem that there appears to be a lack of good sample lessons in the teaching of stoichiometry in order to develop student understanding.

[1] Specialized knowledge base for teaching that has been articulated for teaching specific subject matter knowledge to specific students and is shared among a group of professionals.
[2] The cumulative knowledge and skills of an individual teacher that reflect the teacher's own teaching and learning experiences.
[3] The knowledge and skills an individual teacher uses in a particular setting with a particular group of learners to learn a specific concept or collection of concepts

The construct of TSPCK, defined in the theoretical framework of this study, provides a useful framework for teachers to develop the capacity to think about the concepts of a topic in specific ways that transforms and re-packages them for teaching (Mavhunga & Rollnick, 2013). For the context of this study, the re-packaging for teaching refers to both the planning and enactment, which informs practice in particular classroom contexts (Rollnick & Mavhunga, 2015). Teaching is therefore viewed as a thinking process, since a large portion of the psychological context of teaching is comprised of thinking, planning and decision-making, and teachers' knowledge acts as a resource for this thinking process (Brodie, 2004; Clark & Peterson, 1986). Since a Learning Study is a systematic and well-articulated process for examining practice and is a powerful tool for improving teaching strategies (Fernandez, 2002; R. Stewart & Brendefur, 2005), this will serve a vehicle to form a Professional Learning Community for experienced practising teachers to discuss, reflect on and inform their practice, with the construct of TSPCK forming the grammar of practice within this community (Baird, Fensham, Gunstone, & White, 1991; Brodie, 2011; Grossman, 2011).

The main focus of this study is centred around investigating the gap in knowledge related to describing enacted TSPCK in classroom practice when teachers' collaborate in planning to teach a difficult topic. The impact of this collaboration in a Professional Learning Community of teachers involved in a Learning Study on the participants' TSPCK development and the actual enactments in classroom practice will be explored. However, the quality of the TSPCK of the practising teachers is an unknown variable that needs to be identified and described through measurement (Gess-Newsome, 2015) for this study. Since there were no existing instruments to measure TSPCK for the topic of stoichiometry, instruments had to be designed not only to measure the quality of teachers' TSPCK but also to measure the change in TSPCK through participation in a Learning Study (Malcolm, 2015).

The main research question for this study, with reference to the above, is therefore formulated as follows: 'To what extent is experienced science teachers' measured and enacted TSPCK developed during a Learning Study designed with the explicit inclusion of TSPCK for the topic of stoichiometry?'

The research question has the following sub-questions:

1. What is the baseline quality of experienced physical sciences teachers' topic-specific PCK and content knowledge in stoichiometry of teachers teaching in the province of Gauteng?

2. How and to what extent is the topic-specific PCK of experienced teachers developed through participation in a Learning Study?

3. How and to what extent is the collective topic-specific PCK evident in a Professional Learning Community enacted in the teaching practices of the teachers teaching the mole concept?

1.7. The Researcher and Positionality

The methodology employed in this study is that of mixed methods which, according to Tashakkori and Creswell (2007), is the collection and analysis of both qualitative data and quantitative data and the integration of qualitative and quantitative approaches. The methodology is described in detail in Chapter 3. Qualitative and quantitative approaches are built on philosophical differences in the structure and confirmation of knowledge (Foss & Ellefsen, 2002). Therefore, as Mavhunga (2012) outlines, for the qualitative aspect of this study, it is important to provide a personal account of myself as a researcher and the possible ways this has influenced the results. What follows is a brief description of myself as a researcher and a reflection of how my positionality may have interacted with the conducted research.

I am a white male, born in Johannesburg to a working class, English-speaking family. My schooling began in the mid-seventies and was completed in the late eighties. Throughout my schooling I was focused on one goal and that was to become a teacher. I was a conscientious student since my family was not in the financial position to fund my tertiary education. Fortunately, I was able to secure a bursary and I was the first member of my family to receive tertiary education. In my initial B.Sc degree, I majored in Zoology and Botany. I began my teaching career in the early nineties and then moved on to work for the ASECA programme, a project of SACHED Trust. It was here that my deep conviction of 'quality education for all South Africans' was cemented. I was involved in developing outcomes-based science materials, developing assessment tasks and teacher training. I returned to teaching in 2003

and began teaching Physical Sciences. I embarked on a series of courses to improve my content knowledge, firstly completing Physics I and some Chemistry II modules through UNISA, before registering for a post-graduate degree in science education in 2010. During my postgraduate studies, I was introduced to PCK and it sparked my interest due to its 'facilitating student understanding'(Van Driel & Berry, 2010). During the Learning Study, I was both the facilitator of the group and taught the first cycle of the lesson. I was therefore a participant observer. This active involvement and my assumptions of what it is to effectively teach stoichiometry developed from the instrument design (Malcolm, 2015) and potentially created a degree of subjectivity. However, working with other researchers at the university investigating TSPCK helped create a system of checks and balances during the analysis and interpretation of data. My role as a researcher is outlined in more detail in Chapter 3.

1.8. Structure of the Thesis

This thesis consists of eight chapters and is structured to represent the two distinct phases of this mixed methods study. The two distinct phases relate to determining the baseline quality of teachers' TSPCK for which an instrument was designed and the formation of the Professional Learning Community to develop teachers' TSPCK. The design and validation of the TSPCK instrument in stoichiometry was part of my M.Sc research and is reported on in an unpublished manuscript (Malcolm, 2015) since the study was upgraded to a doctoral dissertation. The outline provided below summarises the various aspects discussed in each of the chapters.

Chapter One provides the introductory discussion and starts with a preamble hinting at the problems associated with stoichiometry and a brief glimpse at PCK and its measurement. It then identifies the problem and locates this within the South African context. The rationale for the study is outlined and research questions that guided the study are provided. Finally, the positionality of the researcher and the structure of the report are presented at the end of the chapter.

Chapter Two presents a review of the literature and consists of two thrusts. The first is a review of the literature relating to teacher knowledge and effective teaching in the classroom, the main themes of this study. Since PCK is topic-specific, the second thrust of this chapter focuses on a review of the literature that highlights why stoichiometry is a problematic topic to teach. The theoretical framework is then discussed.

Chapter Three describes the research methodology used in this study. This includes the mixed method approach for instrument design, and examining TSPCK development and TSPCK classroom enactment. The instruments for data collection and the analysis of data methods are described. Issues relating to validity and credibility, and ethical considerations are then presented. The chapter closes by discussing the issues related to reflexivity.

Chapter Four describes the quality of teachers' TSPCK as garnered from the TSPCK instrument and the quality of teachers' CK. The chapter also describes the sampled teachers' conception of the mole. Descriptions of both the quantitative and qualitative analysis of the responses to the TSPCK and CK instruments are provided in order to develop holistic profiles of approaches to teaching stoichiometry.

Chapter Five begins by developing a working definition for a Professional Learning Community. The chapter then outlines the formation of the Professional Learning Community, outlines it values and describes its goals. Thereafter it provides an outline of the activities of the Professional Learning Community, including the Learning Study.

Chapter Six looks at the TSPCK development of the teachers involved in the Learning Study. This chapter firstly describes how the change in teachers' TSPCK was determined using Rasch analysis. Next, it provides a narrative analysis to account for the change in scores for the TSPCK components of the teachers participating in the Learning Study.

Chapter Seven describes the quality of the teachers' enacted TSPCK when teaching the lesson developed in the Learning Study. This is done by comparing the lesson taught by the teachers involved in the Learning Study with a comparison group of teachers' lessons. The chapter describes how TSPCK episodes were identified and described pictorially in TSPCK episode maps. These TSPCK episode maps were then scored using an enactment rubric, in order to compare the quality of the lessons taught by the two groups of teachers.

Chapter Eight summarises the study with discussions of the findings in an attempt to answer the research questions. Where applicable, conclusions are drawn and the implications related to the findings, including contributions to the field of TSPCK research and PCK research, are discussed. Recommendations based on the findings are suggested along with avenues for future research and the limitations of the study are presented. The chapter ends with critical reflections of the process and its impact on developing my own PCK in stoichiometry.

CHAPTER TWO

Literature Review and Theoretical Framework

This chapter reviews the literature relevant to the study. It also provides an overview of the theoretical framework that guided the study. Firstly, this section describes aspects of teacher knowledge and focuses specifically on PCK. This chapter also describes aspects of effective teaching and particularly links effective teaching to PCK, reflection and collaboration. Literature related to the mole concept, a central aspect when teaching stoichiometry, and the difficulties this concept poses in the learning and teaching of stoichiometry is also reviewed. An overview of learner difficulties in stoichiometry and conceptual teaching strategies is provided. The mole is defined and various conceptions of the mole are discussed, as is the impact this has on teaching the mole concept. Finally, the different theoretical aspects that guided this study are outlined and brought together in the theoretical framework of this study.

2.1. Overview

This study is placed within the context of teacher knowledge and the enactment of this knowledge when teaching in the classroom. As such, it is placed within two distinct modes of thought: the paradigmatic, since teacher knowledge is often expressed as propositions; and the narrative, since teachers often express their knowledge as stories (Munby, Russell, & Martin, 2001). The purpose of the literature review is therefore twofold. Firstly, it summarises both the past and current state of research relating to teacher knowledge within these two modes of thought, its development and the impact of teacher knowledge on classroom practice (Creswell, 2012). Secondly, it establishes a link between existing knowledge in the field of PCK and the research problem of this study. This is done in order to document the need for the current study and its significance in the field (McMillan & Schumacher, 2010). Loughran (2010, p. ix) states that 'there is considerable literature describing the diversity of views on the nature of teachers' professional knowledge of practice'. Therefore, the literature review aims to provide an overall picture of research into teacher knowledge, specifically PCK, since the construct of topic-specific PCK is the lens selected to explore how teacher knowledge impacts on classroom enactment.

2.2. Teacher Knowledge

Teaching lies at the heart of education and is intended to lead towards learning (Gage, 1984; Shulman, 2004a). Simply, teaching can be described as a process in which a provider who possesses some content and a recipient who lacks the content engage in a relationship in order for the recipient to acquire the content (Fenstermacher, 1986). In terms of teaching and learning, there are many skills that make a competent teacher (Loughran, 2010). A large body of research, referred to as process-product research, exists that reports on the observation and measurement of these skills, attributes of teacher behaviour and the observable performance of teachers (Shavelson, Webb, & Burstein, 1986; Shulman, 1986a, 2004a). This research has focused on studies relating to teacher planning, classroom processes, teaching outcomes and the multilevel contexts in which teaching occurs and has contributed to our understanding of successful teaching (Brophy & Good, 1986; Rosenshine & Stevens, 1986; Shavelson *et al.*, 1986). Teaching also includes cognitive dimensions such as comprehension and interpretation, and skills such as recognising when to act and how to improvise (Doyle, 1986). According to Clark and Peterson (1986), in order to understand how and why teaching works, an understanding of teachers' thought processes, which includes teacher planning, interactive thoughts and decisions and beliefs is essential. According to Loughran (2010), the actions taken by teachers in their classroom develop their professional knowledge of practice. However, as Shulman (2004a) highlights, a failing of both policy and the assessment of teachers using the competencies generated through process-product research is that it typically rests on an incomplete and partial view of teaching. According to Shulman (1986b, 2004a), an important aspect of research on teaching was ignored in process-product research, which he referred to as the 'missing paradigm'. The latter was that of understanding the content to be taught and the knowledge base for teaching that underpins teachers' professional knowledge of practice.

Research on teacher knowledge and its central role in educational processes is a fairly recent area of education research and, until about thirty years ago, emphasis was on teacher attributes and behaviour, including planning, classroom management and organisation (Carter, 1990; Shulman, 1986b; Verloop, Van Driel, & Meijer, 2001). Shulman's (1986b) seminal address expressed the need for a coherent framework of teacher knowledge, that went beyond mere pedagogy and the restrictive definitions of knowledge for teaching based on behavioural prescriptions (Verloop *et al.*, 2001). However, according to Munby *et al.*

(2001), the nature and development of teacher knowledge is only beginning to be understood and one of the main dichotomies relating to teacher knowledge is the divide between theory and practice.

Carter (1990) broadly categorises the approaches to understanding teacher knowledge and how this knowledge develops into three categories. The first category of teacher knowledge is information processing and includes teacher decision-making. It has focused on the contrast between novice and experienced teachers. The second is practical knowledge and includes personal and classroom knowledge that allow teachers to navigate the complex classroom setting. The third is pedagogical content knowledge, or the ways teachers understand and represent subject matter to students. Although there are areas where these three categories overlap, each operates under different assumptions, theoretical frameworks, emphases or methodological commitments, highlighting the epistemological complexity of teachers' knowledge (Carter, 1990; Munby *et al.*, 2001). Teaching can therefore also be described as a complex cognitive skill, involving an abstract knowledge structure, or schema, and pedagogical reasoning (Livingston & Borko, 1989).

The information processing category of understanding teacher knowledge, according to Carter (1990), typically focuses on the cognitive processes teachers use in thinking about the teaching process, typically based on classroom practice and planning. Much of this research focused on teacher decision-making to improve understanding of the psychological context of teaching which explains the reality of practice (Walberg, 1977; Whitfield, 1977). Much of the research done on teacher decision-making has focused on primary school teachers rather than secondary school teachers in a First World context (Stoffels, 2004). In South Africa, studies of teacher decision-making have been conducted looking at decision-making processes related to instructional strategies and the use of learner support materials in the context of curriculum change (Stoffels, 2004, 2005). In the classroom setting, researchers have embraced digitisation by using video-stimulated recall interviews (SRIs) as a research method to understand teacher decision-making processes (Nguyen, McFadden, Tangen, & Beutel, 2013). However, like the process-product research, by focusing on a few characteristics of teacher thinking, the focus was more on the process of teacher thinking, rather than the knowledge used by teachers to interpret situations, formulate plans or make decisions (Carter, 1990; Shulman, 1986b).

The second category of understanding teacher knowledge, that of practical knowledge, emphasises the classroom knowledge related to the complexities of interactive teaching and thinking-in-action (Carter, 1990). According to Munby *et al.* (2001), this knowledge is anchored in classroom situations that include the practical dilemmas encountered by teachers, and include both personal and practical knowledge based on the personal understanding teachers have of the practical circumstances in which they work. It is within this context that Loughran (2012) describes teaching as problematic since individual experience shapes a teacher's understanding of the teaching role in practice.

This practical knowledge develops through personal experience (Field & Latta, 2001). In this context, experience refers to what is gained from a teacher's environment, the classroom and their own inner reality while relating to the environment (Lunenberg & Korthagen, 2009). This inner reality, according to Lunenberg and Korthagen (2009), encompasses know-how, beliefs about practice and a sense of professional identity developed through personal perceptions of the encounters within the environment. Shulman (2007) makes a distinction between practice, as what teachers do and the wisdom of practice, as the range of practical arguments, including theoretical, practical, critical and normative assertions used by teachers as they reason about and make judgements about situations they confront and the actions they take. According to Shulman (1987, 2004c), wisdom of practice, which guides the practices of effective teachers in which they make professional judgements in a complex task, is gained with experience.

Research, therefore, on this practical knowledge focuses on the personal understanding teachers have of the practical circumstances in which they work and is shaped by a teacher's personal history (Carter, 1990). This kind of teacher knowledge, due to the unique context of the classroom, is often expressed in a narrative mode of anecdotes and stories (Munby *et al.*, 2001). The domains of practical knowledge include knowledge of self, knowledge of the milieu of teaching, subject matter, curriculum development and instruction (Munby *et al.*, 2001). According to Carter (1993), the narrative story has become a central focus in research on teaching, to capture the richness of a teacher's experiences and the complexity of understanding teaching. In these studies, the metaphors used by participants to describe the task of teaching are considered significant indicators of their beliefs and how teachers construct professional knowledge (Kalra & Baveja, 2012; Munby, 1986). As such, this aspect of teacher knowledge is researched qualitatively using narrative inquiry since it describes

human action (Polkinghorne, 1995). With such narrative inquiry, description is used to tell a time-bound story (Zeller, 1995). However, research in the area of teachers' personal knowledge does not result in generalised conceptions of teachers' knowledge, but rather provides a theory of how teachers learn from teaching and how this knowledge is used (Carter, 1990; Munby *et al.*, 2001).

Only the third category of teacher knowledge will be explored here since topic-specific PCK is the lens through which teacher practice will be investigated in this study. The reasons for this are that, firstly, practical knowledge, due to the unique context of the classroom, is often expressed in a narrative mode of anecdotes and stories to capture the richness of a teacher's experiences (Carter, 1993; Munby *et al.*, 2001). Secondly, research in the area of teachers' personal knowledge does not result in generalised conceptions of teacher knowledge (Carter, 1990; Munby *et al.*, 2001). Thirdly, like the process-product research, information-processing focuses only on the process of teacher thinking rather than the knowledge used by teachers to interpret situations, formulate plans or make decisions (Carter, 1990; Shulman, 1986b).

Pedagogical content knowledge is one of the categories of knowledge within the professional knowledge bases for teaching proposed by Shulman (1987) needed by teachers to promote student understanding, which was unique to teachers. This knowledge included seven categories of knowledge required for teaching (Bishop & Denley, 2007; Shulman, 1987). PCK has been described as the most influential of the content-related categories of teacher knowledge (Ball *et al.*, 2008). Shulman (1987, p. 8) describes PCK as 'an amalgam of content and pedagogy that is uniquely the province of teachers'. This knowledge possessed by teachers, is transformed to develop learners' knowledge, skills and understanding through pedagogical representations and actions and translated into classroom curricular events (Carter, 1990; Shulman, 1987). Broadly, PCK can be defined as the 'teachers' understanding of how to assist learners understand specific content knowledge' (Magnusson *et al.*, 1999, p. 96). Cochran, King, and DeRuiter (1991, p. 11) defined PCK as the way in which teachers relate pedagogical knowledge to their subject matter knowledge within a school context for teaching specific students. According to Veal and MaKinster (1999), this view of PCK, which they refer to as '*PCKing*', is more an action than a form of knowledge. Loughran *et al.* (2012, p. 9) provide a more expanded definition of PCK, defining it as 'the knowledge that teachers develop over time, and through experience, about how to teach particular content in a particular order to lead to enhanced student understanding'.

The various definitions have highlighted the differences of thinking about PCK by researchers in the field (Gess-Newsome, 2015). Despite the concerted efforts of researchers in the field to define, describe and categorise the knowledge included in the concept of PCK (Bishop & Denley, 2007; Padilla & Garritz, 2011; Park *et al.*, 2011), according to Ball *et al.* (2008) until recently researchers have been unable to establish a precise, or universal definition of PCK. At a recent PCK summit in Colorado, however, strides were made at developing a consensus definition of PCK (Gess-Newsome, 2015). This definition consists of two components and incorporates both the notion of PCK as a knowledge component and an action. This consensus definition defines PCK as 'knowledge of, reasoning behind, and planning for teaching a particular topic in a particular way for a particular purpose to particular students for enhanced student outcomes' and 'the act of teaching a particular topic in a particular way for a particular purpose to particular students for enhanced student outcomes (Gess-Newsome, 2015, p. 36). Carlson and Daehler (in press) have recently articulated this definition as two distinct, yet related forms of specialised knowledge, namely personal PCK (pPCK) and enacted PCK (ePCK). They describe pPCK as the cumulative knowledge and skills of an individual teacher that reflect the teacher's own teaching and learning experiences. When planning, enacting, or reflecting on teaching a specific topic to specific learners, in other words engaging in the practice of teaching, the teacher utilizes ePCK. This form of specialised knowledge in action takes cognisance of the 'skills' included in the consensus definition of PCK and ePCK is used in practice when teachers access their pPCK.

The consensus definition of PCK, however, is applied to personal PCK and how it is accessed during teaching. Therefore pPCK and ePCK are contextual rather than canonical PCK, which is topic-specific and can be established by systematic research best practices (Garritz, 2015; Gess-Newsome, 2015; Rollnick & Mavhunga, 2015). This canonical PCK has recently been articulated as collective PCK, and is described as the specialised knowledge shared among a group of professionals for teaching specific subject matter knowledge to specific students (Carlson & Daehler, in press). Since PCK is the lens through which teacher practice, specifically planning and enactment will be investigated in this study, a more detailed account of capturing and portraying PCK is described below.

2.3. Capturing and Measuring Pedagogical Content Knowledge

The usefulness of the construct of PCK for practising teachers due to the lack of consensus about its meaning has been questioned (Corrigan, Gunstone, & Dillon, 2011). Abell (2008, p. 1413), however, argues that for science education research, the construct is useful and there are still many unanswered questions, including not knowing enough about the 'PCK science teachers have, how they come to have it, and what they do with it'. Loughran *et al.* (2012) have also criticised much of the research done on PCK as not being linked to finding ways to help teachers improve their practice, by focusing on the evaluation of PCK rather than attempting to explore specific examples of how specific topics are taught. This study, as outlined in the section on the purpose of this research, aims at investigating the impact of experienced teachers working collaboratively on their PCK development and enactment in the classroom. As such, capturing teachers' PCK and the development of PCK are central to this study and an overview of the literature relating to these aspects is outlined here.

In order to capture or measure PCK, due to the lack of clarity of its definition, there have been a large number of studies that have explored the components of PCK to clarify the construct (Hu, 2014). As a result, various models to describe teachers' PCK exist, all modified in different ways from Shulman's original proposal (Kind, 2009b). For the purposes of this study, PCK is viewed as a form of knowledge synthesised by teachers that develops through the transformation of teachers' content knowledge, pedagogical knowledge and contextual knowledge in planning to teach and used in practice when teaching (Godino, Batanero, Roa, & Wilhelmi, 2008; Kind, 2009b). As such, this implies a mechanism that uses content knowledge in creating PCK and adapting PCK for school use during enactment when teaching (Kind, 2009b). Ball *et al.* (2008) have criticised many studies on PCK for their lack of attention to specific areas of content. Veal and MaKinster (1999), in their taxonomy of PCK, describe topic-specific PCK as the most specific and novel level of PCK and, based on the inherent differences in the domains of science, argue for a similar distinction to be made within topics in a domain as support for topic-specific PCK. One of the issues to be considered when measuring PCK is the issue of 'grain-sized' measurements within a domain, or, even more specifically, topics within a domain (Gess-Newsome, 2015). This is the reason for using topic-specific PCK as the theoretical lens in order to measure and capture teachers' PCK for this particular study, which is outlined in the theoretical framework of this thesis.

The development of the various models for PCK, whether general, at a subject or discipline level (e.g. Grossman, 1990; Magnusson *et al.*, 1999) or topic-specific (e.g. Geddis & Wood, 1997; Hashweh, 2005; Mavhunga, 2012) have aimed at describing PCK and/or focused on the measurement and development of teachers' PCK (Abell, 2008). There have been many studies using a variety of multi-method research approaches that have looked at the development of PCK in teacher preparation programs (e.g. De Jong, Van Driel, & Verloop, 2005; Geddis, Onslow, Beynon, & Oesch, 1993; Veal, Tippins, & Bell, 1999), including how the explicit inclusion of the construct of topic-specific PCK can facilitate pre-service teachers' PCK development (Mavhunga, 2014). Other studies have focused on describing and/or representing the PCK of experienced teachers (e.g. Davidowitz & Rollnick, 2011; E. Lee & Luft, 2008; Padilla, Ponce-de-León, Rembado, & Garritz, 2008) or investigating the impact of content knowledge on PCK development either at a planning level or in practice (Hashweh, 1987; Rollnick *et al.*, 2008). Studies of experienced teachers' PCK development have also been conducted in a variety of contexts, including the use of educative materials (e.g. Carlson, Gess-Newsome, Gardner, Wilson, & Stuhlsatz, 2010; Schneider & Krajcik, 2002), teaching a new topic (e.g. Chan & Yung, 2015; Henze, Van Driel, & Verloop, 2008), the use of inquiry-based approaches to teaching (Park *et al.*, 2011) and in professional development programs (Anney & Hume, 2014; Drechsler & Van Driel, 2008; Nilsson, 2014). As is evident from the literature experienced teachers PCK development is well documented. However, only the study conducted by Mavhunga (2012) has focused on topic-specific PCK development with pre-service teachers. This study focuses on experienced teachers' topic-specific PCK development within the context of a Learning Study as a professional development activity.

2.3.1. Investigating PCK Development in a Learning Study

For the purposes of this study, practising teachers' PCK development was investigated in a Professional Learning Community engaging in a Learning Study as a form of professional development. Professional learning is not necessarily confined to in-service programmes and teachers can learn from each other through collaboration (Floden, 2001). Studies conducted by Nilsson (2014) and Nilsson and Vikström (2015) have shown that participation in a Learning Study has the potential to develop teachers' PCK. These studies have shown that participation in a Learning Study helped teachers to develop and increase knowledge about the relationship between subject content, teaching and learning, or knowledge about the

curriculum. These studies have also shown that teachers' developed a clearer conceptualization of student understanding and the content representations, examples and instructional strategies they use.

Learning Study, derived from Lesson Study, represents an example of a systemic and well articulated process for examining practice. The key difference between a Lesson Study and a Learning Study is that variation theory underpins the features of instructional design and the lesson development in terms of student learning (Pang & Ling, 2012). In both a Lesson Study and Learning Study, the process begins with teachers setting a goal for the lesson. They come together, meticulously plan the lesson collaboratively and produce a lesson plan. The lesson is then taught by one of the educators and observed by others in the group, who take careful notes or alternatively the lesson can be video-taped (Fernandez, 2002, 2005). The group then reconvenes after the lesson has been taught to share their observations and reactions to the lesson. The group can then modify or revise the lesson plan (Fernandez & Chokshi, 2002).

As has been mentioned the key difference is the use of variation theory, which is used as a framework to guide teachers' practice to provide students with the necessary learning opportunities to understand a concept (Nilsson & Vikström, 2015). Variation theory requires teachers to focus on a particular concept and how students understand that concept by focusing on the various ways students experience the concept and therefore is used as a way to explain learning in the classroom (Lo & Chik, 2016; Marton & Pang, 2006). Not only does variation theory explain learning but it specifically is used by teachers to structure a learning situation that makes it easier for to learn a concept (Pang & Marton, 2007). A more detailed account of variation theory is included in Appendix A16.

A Learning Study is time consuming since Learning Study groups need to meet at least once a week. To maximise the time available, strategies can be used to make efficient use of the time available, such as role assignment or distribution of materials for feedback beforehand. Sustained Lesson Studies can help teachers build a shared body of professional knowledge (Chokshi & Fernandez, 2004), since the process of developing detailed lesson plans and discussing it with colleagues has proved a powerful tool for instructional improvement (R. Stewart & Brendefur, 2005). Learning Study, however, incorporates other features central to PCK development. These features include a reflection on practice and learning from experience. According to Loughran (2010), expert teachers consider how various teaching and learning procedures impact on their practice. Reflection is not only a means to improve

practice but also enables teachers to learn about teaching (Loughran, 2010; McAlpine & Weston, 2000). According to Shulman (2004b), in order for teachers to learn from experience they need to reflect on their teaching. In other words, it requires a teacher to look back at the teaching and learning that has occurred (Shulman, 1987). Reflection is central to Shulman's notion of pedagogical reasoning. The last process of pedagogical reasoning, which he refers to as a new comprehension, is linked to learning from experience (Shulman, 1987). In order to learn from experience, teachers need opportunities to communicate face-to-face in order to deliberate and analyse experiences, and be provided with opportunities to communicate what they have learned from experience and to discuss ways to improve instruction (Floden, 2001; Hopkins & Stern, 1996; Shulman, 1987). However, this goes beyond the mere exchanging of ideas with colleagues; it involves planning in teams and teaching together (Hopkins & Stern, 1996). Such collaboration can assist teachers to break down barriers and encourage learning about teaching (Loughran, 2010). This can be achieved when teachers work together in a Professional Learning Community.

2.3.2. The Value of Professional Learning Communities in Teacher Learning

According to Stoll and Seashore Louis (2007), there is no universal definition for professional learning communities, or PLCs. They do, however, state that one exists when a group of teachers share and critically interrogate their practice in a reflective, collaborative, inclusive, learning-orientated and growth-promoting way. The impact of PLCs on teacher learning has been shown to be significant in a number of studies (e.g. Borko, 2004; Brodie, 2013). PLCs not only contribute to teacher development but can have significant benefits for student learning as teachers improve their practice (Hargreaves & Fullan, 2012; Reichstetter, 2006). A PLC was the central feature around which teachers' TSPCK development and classroom enactment were investigated and Chapter 5 of this thesis provides a more detailed account of the benefits, the characteristics and the activities of a PLC, specifically in the context of this study. In order to determine the impact of working collaboratively on PCK development in a PLC, it was necessary to determine the extent of practicing teachers' PCK through measurement.

2.3.3. Measurement of PCK

Many researchers have attempted to develop instruments to quantitatively measure teachers' PCK. Quantitative studies, which utilise paper-and-pencil tests without interview protocols or observations have the potential to provide more generalisable results for PCK measurement (Borowski, Carlson, Fischer, Henze, Gess-Newsome, Kirschner, & Van Driel, 2012). Multiple choice tests, for example, can allow for a shift from small-scale studies to large-scale studies that measure teachers' PCK and have clear advantages compared to qualitative methods. Work has been done by Rohaan, Taconis and Jochems (2009, 2011) in which they constructed and validated a multiple choice test to assess primary school teachers' PCK in technology education but produced low reliability results. Baxter and Lederman (1999) question how well teachers' performance in such multiple choice tests reflects classroom instruction. The use of qualitative methods to measure PCK is both time consuming and labour intensive, and the use of purely quantitative methods, such as multiple choice tests that are both time and labour efficient, and can be used to collect data from larger sample sizes, may overlook the essence of PCK (Baxter & Lederman, 1999; Rohaan *et al.*, 2011).

A possible solution to the above dilemma is to include examples of manifestations in the classroom, such as the selection of representations, topic-specific teaching strategies, curricular saliency and assessment as evidence of PCK in instruments designed to measure PCK (Baxter & Lederman, 1999; Rollnick *et al.*, 2008). The use of paper-and-pencil instruments that utilise such manifestations could provide a more balanced view of measuring PCK on a larger scale. A number of studies have used such paper-and-pencil instruments with both multiple choice items and open-ended items. In one such study the multiple choice items were developed from relevant solutions drawn from empirical studies, theories in science teaching and learning and these items were used to measure primary school science teachers' PCK (Lange, Kleickmann, & Moeller, 2009). Another quantitative study conducted by Kirschner, Borowski & Fischner (described in Borowski *et al.*, 2012) measured the PCK of German Physics teachers using open-ended and multiple choice items. Construction of an instrument that measures topic-specific PCK in chemical equilibrium that required participants to apply their content knowledge and reasoning, utilising a topic-specific model of PCK has been developed, piloted and validated (Mavhunga & Rollnick, 2013) and

produced high reliability indices. The topic-specific, or TSPCK model, developed by Mavhunga (2012) has been used successfully to develop a number of instruments to measure TSPCK in chemistry topics (e.g. Ndlovu, 2014; Pitjeng, 2014; Vokwana, 2013) and a physics topic (Zimmerman, 2016). The need to measure teachers' PCK on a larger scale is central to this study as a means of identifying teachers to participate in the Learning Study to examine classroom enactment and PCK development.

With the reconceptualization of PCK at the PCK summit in Colorado, such paper-and-pencil instruments are seen to measure canonical PCK, referred to as topic-specific professional knowledge, that can be substantiated with systematic research and shared with others, and can serve as a framework for professional development (Garritz, 2015; Gess-Newsome, 2015). The translation of teachers' knowledge, the first aspect of PCK, into classroom practice or enactment, the second aspect of PCK, is clearly a critical component of PCK. This therefore obligates researchers to observe actual teaching segments since teachers' actions are a manifestation of teacher knowledge and therefore a more accurate representation of teachers' knowledge (Baxter & Lederman, 1999; Loughran, 2012). However, Baxter and Lederman (1999) state that research that relies primarily on teachers' actions to assess teacher knowledge is also problematic. The low correlations of the process-product research on teaching suggest that myriad factors influence classroom instruction (Brophy & Good, 1986). Consequently, the level of consistency between teachers' observed behaviour and their knowledge is highly variable. Just as a narrow focus on knowledge limits our understanding of PCK, an overemphasis on classroom practice may well present a distorted view of teachers' knowledge (Baxter & Lederman, 1999).

Due to the problems outlined above Morrison and Luttenegger (2015) recommend that multiple data sources be used to measure teachers PCK. Teachers' decision-making, the third aspect of PCK, is a complex and slippery construct to study. Simply by asking a teacher to state reasons for a particular teaching action, we risk changing the teacher's decision making process. As Kagan (1990) has suggested, many teachers have highly personalised perceptions of teaching that may be extremely difficult to communicate to an educational researcher. However, video-SRIs are a valuable tool that can be used effectively in capturing teacher decision-making (Nguyen *et al.*, 2013) during enactment when teachers draw on their specialised knowledge bank and repertoire of pedagogical moves to respond to a particular situation (Carlson & Daehler, in press). The assessment of PCK is difficult and fraught with

hazards, as it requires a combination of approaches so that information can be gathered about what teachers know, what they believe and the reasons for their actions. Assessment of any aspect of PCK in isolation of the other two incurs a significant risk of distorted meaning and interpretation (Baxter & Lederman, 1999), and hence the use of the model for teacher knowledge outlined in the theoretical framework described in Section 2.6 and a mixed methods approach (described in Chapter 3).

2.3.4. Filters and Amplifiers

The model for teacher knowledge described by Gess-Newsome (2015, p. 34) acknowledges that the knowledge held by the teaching profession, which is accessed by teachers, has to 'pass through the lens of the teacher'. Teachers, as free agents can embrace, modify or reject any new knowledge, skills or practices based on their beliefs. These beliefs impact on teachers' orientations towards science teaching that guide instructional decisions and influence the preferred organization of content for the discipline they teach (Gess-Newsome, 2015; Magnusson *et al.*, 1999). These beliefs therefore shape the way teachers understand teaching and the priorities they give to the different dimensions of teaching (Tsang, 2004). According to Wong and Luft (2015) beliefs have an undeniable impact on teachers' decisions. According to Blonder, Benny, and Jones (2014) the construct that underlies a teacher's selection of instructional strategies, knowledge bases and classroom enactment is self-efficacy. According to Bandura (1997) self efficacy relates to a person's personal beliefs about their capabilities to produce designated levels of performance that exercise influence over events. This integrated system of past experiences that included success and failures, feedback from others; shape how teachers implement new ideas and influence the effectiveness of professional development. Teacher beliefs, particularly teachers' beliefs about their professional actions, also impact on aspects of professional development (Lumpe, Vaughn, Henrikson, & Bishop, 2014). Although teacher self-efficacy has been proved to be linked to teachers' instructional behaviour, the construct is difficult to measure (Tschannen-Moran & Hoy, 2001). For this reason, although not the primary focus of this study it is important to acknowledge the explanatory power of beliefs as a filter or amplifier in teachers' PCK development and enactment in the classroom (Gess-Newsome, 2015).

2.4. Effective Teaching

When undertaking research on teaching, Fenstermacher (1986) states that the researcher generally undertakes the study with either a presupposed or unconscious assumption of what teaching is. Fenstermacher (1986) outlined the basic characteristics of teaching, described earlier. According to Shulman (1987), teaching begins with a teacher's understanding of what is to be taught, which is then enacted in practice. It ends with comprehension of not only the learner, but also the teacher, and additionally for the latter, an improvement in performance over and above enhancement of understanding. He outlines the processes of teaching which he feels teachers should show the capacity to engage in - pedagogical reasoning (Shulman, 1987). This begins with the teacher's comprehension of the material that needs to be taught, its transformation into a teachable form, the actual instruction in the classroom, evaluation, reflection and a new comprehension which includes learning from experience.

2.4.1. Lesson Planning and Effective Teaching

Novice teachers generally begin this process in pre-service training programs through lesson planning (John, 2006). There are many models for planning effective lessons, such as the Hunter and Russell (1976) model, with key lesson elements that are research-based from the process-product research paradigm (Wolfe, 1987). These lesson elements are discussed in the theoretical framework in this chapter as they were used as an analytical framework when analysing TSPCK enactment in the classroom. Loughran (2010) associates many of these practices as core features of expert teachers. Lesson planning is considered key to effective teaching but the task is most often technical and does not promote pedagogical reasoning (Ashcraft, 2015; Rusznyak & Walton, 2011). However, when teachers approach lesson planning in a manner that promotes pedagogical reasoning by considering the pre-requisite knowledge students require to understand a topic, learner prior knowledge and predict students' potential learning difficulties they are able to implement instructional strategies that develop student understanding (Chan & Yung, 2017). According to Chan and Yung (2017) such an approach to lesson planning, which is dependent on an individual teacher's commitment to lesson planning, develops a teacher's PCK. According to Stender, Brückmann, and Neumann (2017), lesson planning is also considered the driving force in a teacher developing teaching scripts, mentally stored instructional scripts developed over time from lesson planning and reflection which they draw from in classroom teaching. These

ideas, linked to effective lesson planning therefore featured when examining the practice of experienced teachers in this study. But what factors influence the way experienced teachers plan for effective lessons?

2.4.2. Effective Teaching, PCK and Instructional Strategies

Whether describing classroom enactment or conceptions of professional knowledge, the notion of effective teaching is a recurrent idea. Parental intuition, often supported by research, is that their children learn more from some teachers than others (Mullens, Murnane, & Willett, 1996). Research on expertise in teaching, although informative, has often highlighted the problem of talent versus deliberate practice that brings into question whether teaching is an art or a science (Berliner, 2001; Gage, 1984; Hassard, 2005). Gage (1984) is of the opinion that teaching is an art, but argues that there is a scientific basis for the art of teaching. In other words, there is a scientific basis to study the variables of teaching, which although often showing weak correlations, indicate that teaching can be improved to benefit student achievement.

Quantitative studies have shown that educational attainment of teachers, participation in professional development, subject matter knowledge and teachers' instructional strategies are possible indicators of effective teaching (Mullens *et al.*, 1996). Within Africa, in countries like Nigeria, there is growing concern over the decline in student achievement, despite increased government expenditure on education. Studies have investigated the effectiveness of classroom interactions by teachers on student performance indicating that effective teachers generally produce high performing students whereas ineffective teachers produce poorer performing students (Akiri & Ugborugbo, 2009). Of course, despite a teacher's best efforts, learners may still not engage in the learning process. Student achievement is affected by a myriad of factors (Gess-Newsome, 2015) and linking teacher effectiveness to final examination scores is not a good indicator of teacher quality (Blankstein, 1996).

To assess effective teaching, two requirements need to be met. Previously, effective teaching was outlined as a set of observable performances when describing classroom practice from process-product research (Tuckman, 1995). Although the process-product research described competencies that form part of a teacher's knowledge base, consisting of broad principles and strategies of classroom management and organisation that transcend subject matter or pedagogical knowledge, other aspects of teacher knowledge were omitted from such

descriptions of effective teaching (Shulman, 1986b, 1987). Considering these, an effective teacher could therefore be described as a teacher whose students learn and grow the most; to measure teacher effectiveness requires measuring the students' learning and growth across all learners in the class (Tuckman, 1995). This naturally requires many skills, drawn from the knowledge bases required for teaching, which require refinement and development over time that is the province of experienced teachers rather than novice teachers (Gess-Newsome, 1999b; Loughran, 2012; Shulman, 1987). The characteristics of effective or quality teachers are outlined below as drawn from an international study that looked at policies aimed at improving teaching (Hopkins & Stern, 1996).

Firstly, effective teachers possess not only the necessary content knowledge, but the 'know how' to teach it, or possess pedagogical content knowledge that enables them to continually find ways to transform their content knowledge for teaching (Hopkins & Stern, 1996). This implies that expert teachers possess a knowledge structure for their content knowledge that is structured and integrated in their long-term memory and can be retrieved during transformation and used in performance or enactment better than novice teachers (Berliner, 2001; Gess-Newsome, 1999b). According to Bishop and Denley (2007), Shulman considered this transformation as part of a cyclical process which he referred to as pedagogical reasoning. According to Shulman (1987), pedagogical reasoning and action result in a set of strategies needed for teaching a particular topic that result in observable performance when teaching that topic. The transformation of subject matter was described as the process that leads to the development of PCK (Bishop & Denley, 2007; Shulman, 1987).

Generally, PCK allows teachers to be more self-sufficient and relying less on officially approved materials such as textbooks (Gess-Newsome, 1999b). Teachers with good content background are able to use a wide variety of content representations to make the necessary links between the teachers' understanding of the topic and the ideas being constructed by learners (Gess-Newsome, 1999b). Teachers that possess the necessary PCK are able develop meaningful and engaging activities, practices and discussions and are not restricted to learning activities with strict procedural methods (Gess-Newsome, 1999b; Loughran *et al.*, 2012). Adaptation and tailoring relate to fitting the materials selected to the characteristics of the learners being taught so that materials and activities can be designed specifically for the learning context (Bishop & Denley, 2007; Shulman, 1987). PCK allows teachers to use learner understanding of a topic as the starting point of instruction, since they are able to

predict learner difficulties, connect learner comments and questions to the topic and monitor learner understanding since they can discover and act on learners' alternative conceptions (Cochran, 1997; Gess-Newsome, 1999b).

Teachers with good PCK can also allow for greater connections among content topics and use student responses in classroom discourse (Gess-Newsome, 1999b). Teachers that lack the necessary PCK were highlighted by a study, in which the performance of biology students in Lesotho was investigated; teacher ineffectiveness and teachers' inability to transform content knowledge for teaching and assessment, impacted negatively on students performance in biology (Lebata & Mudau, 2014). The authors report that many teachers teaching biology are uncertified since they have no professional qualification and hence lack knowledge of pedagogy. As Hopkins and Stern (1996, p. 505) so eloquently put it, 'knowing how to convey particular concepts, skills and information is what distinguishes good teachers from everyone else'. In the case of the Lesotho teachers mentioned above, effective instructional strategies and teachers' pedagogical content knowledge, or lack thereof, impacted on learner performance.

Secondly, effective teachers use a variety of teaching strategies to incorporate more learner-centered or small group approaches that are in line with contemporary learning theories (Hopkins & Stern, 1996). Loughran (2010) devotes an entire chapter to thinking about learning in which he outlines various learning theories, taxonomies of learning objectives and contrasts deep and surface learning in order to draw attention to the relationship between teaching and learning that lies at the heart of pedagogy. Effective teachers have not only acquired a repertoire of teaching strategies, from which they can select to use at the appropriate time for a particular group of students, but have developed both a theoretical and practical understanding of the philosophies behind these strategies (Hopkins & Stern, 1996). Returning to the study in Lesotho, Lebata and Mudau (2014) report that the biology teachers relied on the traditional teacher-centered approach, rarely using practical work, or even demonstrations when teaching. However, effective teachers do not only have subject-specific didactics in their repertoire but a range of general skills which they can use to develop their subject specificity (Hopkins & Stern, 1996). This, however, requires an organised approach to planning, to seek patterns and relationships rather than separate and isolated events in teaching and learning, that is more evident in expert teachers than novice teachers (Loughran, 2010). Chan and Yung (2017) have illustrated that experienced teachers who approach lesson

planning in this way are able to invent instructional strategies and content representations when faced with student difficulties when teaching new topics.

Effective teachers are able to use cooperative learning strategies, which have been found to enhance student achievement (Hopkins & Stern, 1996). For example, Ganyaupfu (2013) showed that students performed significantly better when student-centered or teacher-student interactive approaches were used rather than a teacher-centered approach, since learners were actively involved in the learning process. However, teacher self-efficacy, a belief of their ability to bring about student engagement, and teacher beliefs related to learning and teaching influence instructional behaviour and methods of instruction (Luft & Roehrig, 2007; Tschannen-Moran & Hoy, 2001). Creating meaningful pedagogical experiences requires the appropriate selection of an appropriate teaching and learning procedure with particular students to enhance specific outcomes and is therefore used for a particular reason (Hopkins & Stern, 1996; Loughran, 2010). This brings us to the third characteristic of effective teachers: reflection.

2.4.3. Effective Teaching and Reflection

According to Loughran (2010), expert teachers not only consider how various teaching and learning procedures impact on student learning but also how this impacts on their practice. Reflection not only is a means to improve classroom enactment but enables teachers to learn about teaching (Loughran, 2010; McAlpine & Weston, 2000). According to Shulman (2004b), in order for teachers to learn from experience, they need to reflect on their teaching and its consequences, such as establishing what students have learnt. In other words, it requires a teacher to look back at the teaching and learning that has occurred (Shulman, 1987). Reflection is a component of pedagogical reasoning, which leads from evaluation in checking learner understanding while teaching interactively, assessing students' work, the teaching performance and the materials used in teaching (Shulman, 1987).

A key aspect of reflection is that it needs to be centred around goals that represent a teachers' expectations or intentions (McAlpine & Weston, 2000). Loughran (2010) also outlines three important attitudes, initially suggested by Dewey for reflection. These are open-mindedness, whole-heartedness and responsibility. Being open-minded, according to Loughran (2010) included being open to new ideas and listening to other ideas, even if they are contrary to your own, and a willingness to admit that your own ideas may be wrong. Whole-heartedness

involves being both enticed and engaged by ideas, and responsibility involves seeking meaning in what has been learnt, considering the consequences of actions and wanting to know why something is worth believing (Loughran, 2010). Effective teachers, therefore, are able to embrace long-term change since they are most often stimulated to reflect on their practice by dissatisfaction with their own practice (Hopkins & Stern, 1996). Such self-regulatory processes as they engage in teaching, distinguishes the expert teacher from the novice teacher (Berliner, 2001). Reflection is an inherent aspect of Learning Study since the teachers participating are required to reflect on the conditions necessary learning specific content and how to meet these conditions in the learning situation (Nilsson, 2014).

Returning to Shulman's idea of pedagogical reasoning, the last process, which he refers to as a new comprehension, is linked to learning from experience (Shulman, 1987). In order to learn from experience, teachers need opportunities to communicate face-to-face in order to deliberate and analyse experiences and be provided with opportunities to communicate what they have learned from experience (Shulman, 2004b). Furthermore, a reflective teacher that shares their experiences not only improves their practice but is actively engaged in developing their professional learning (Loughran, 2010). This leads to the fourth characteristic of an effective teacher, that of collaborating with other teachers (Hopkins & Stern, 1996).

2.4.4. Effective Teaching and Collaboration

Collaboration goes beyond the mere exchanging of ideas with colleagues but involves planning in teams and teaching together (Hopkins & Stern, 1996). Such collaboration can assist in helping teachers break down barriers and encourage learning about teaching (Loughran, 2010). Another, more formal approach to such collaboration is Lesson Study. In Japan, Lesson Study is an officially sanctioned activity that can be enriched by an outside advisor and is enhanced by multiple avenues for dissemination of work on the Lesson Study (Fernandez, 2002). Lesson Study represents an example of a systemic and well articulated process for examining practice. This type of professional development is an example of a situated view of learning, as it is interactive and involves participation in a social practice that can provide a broader framework for understanding and improving educational practice (Greeno, 1997). Therefore, as suggested by Desimone (2009), there is a need to focus on

those characteristics of a Lesson Study that make it effective for teacher learning and changing teacher practice.

According to Lewis (2004), the key features are a focus on a particular topic, especially where a new approach is advocated, the lesson observation and post-lesson discussions of observations, developing an 'eye for the student' and looking for evidence of student learning. Desimone (2009) outlines the various strengths and weaknesses of various data collection methods used to measure teacher professional development such as surveys, observations and interviews. Although surveys receive more criticism in the literature, he argues that each has its merits if best practice is followed hence the use of different data collections methods outlined in Chapter 3. Lesson Studies can be used for practising teachers as a form of professional development and, according to Darling-Hammond and Richardson (2009), research on professional development has shown that collaborative, collegial learning environments that develop communities of practice are effective for implementing change in practice. Currently there is no formal evidence that involvement in Lesson Study improves learner performance, although collection of artefacts can provide a more nuanced picture of learner performance than a snap shot from standard assessment measures, such as standardised tests. Lesson Study has the potential for improvement in both teachers participating and systemic improvement, and can be adapted to suit the needs of the research (Perry & Lewis, 2009). Learning study, which is an adaption of Lesson Study that uses variation theory, is the collaboration of teachers and a researcher in planning a lesson or sequence of lessons that focus on a specific insight, skill or capability that students are expected to develop (Marton & Pang, 2006; Pang & Ki, 2016). It is important to be aware of challenges faced when doing a Lesson/Learning Study in order to make practice both purposeful and powerful. For this study, the investigation of teachers' TSPCK development and impact on practice focused on Learning study rather than Lesson Study. The Learning Study as a form of collaboration is described in detail in Chapter 5.

The Learning Study was selected as the vehicle to examine the development of teachers' TSPCK and impact on enactment in the classroom through the explicit inclusion of the construct of TSPCK, which forms part of the theoretical framework of this study. The explicit inclusion of TSPCK in pre-service teacher education has been shown to not only develop pre-service teachers' planned TSPCK in particular chemistry topics (Mavhunga, 2014), but also allow for the transfer of the skills related to the transformation of content knowledge when

planning other topics (Mavhunga, 2016). However, there is currently little evidence of how the explicit inclusion of TSPCK in professional development activities for in-service teachers develops practising teachers' TSPCK. There are however, a number of studies that provide evidence that the explicit inclusion of PCK as a construct can lead to the development of practising teachers' PCK (e.g. Bertram, 2014; Williams, Eames, Hume, & Lockley, 2012). Both of these studies focused on early-career teachers and used CoRes to articulate and portray teachers' PCK. Therefore, the potential for developing TSPCK through the explicit inclusion of the construct in a Learning Study is promising and worth investigating. There is also a gap in current knowledge about how teachers' TSPCK utilised in planning to teach a particular topic is translated into actual teaching practice, or enacted TSPCK. A recent study has found that the TSPCK of preservice teachers articulated in planning lessons is more complex when enacted due to factors such as student interactions (van der Merwe, 2018). This study aims to contribute to the understanding of the complex nature of TSPCK when moving from reasoning to classroom enactment (Mavhunga & van der Merwe, 2017). In the next section, the topic of focus for the Learning Study (Lewis, 2004) and the difficulties associated with the topic are reviewed.

2.5. Teaching Stoichiometry and Student Alternative Conceptions in Stoichiometry

Since this study deals with measuring and developing TSPCK, Mavhunga (2012) states that it is important to specify the topic in which the exploration occurs. What follows, is therefore a brief definition of stoichiometry and an outline of the major concepts involved in stoichiometry gleaned from chemistry textbooks. Learners have a number of alternative conceptions and difficulties when doing stoichiometric calculations (Fach *et al.*, 2007). Some of the reasons for the difficulties learners have are due to the complexity of conducting these calculations that require an understanding of the mole concept, constructing and balancing chemical equations, algebraic skills, and interpretation of a word problem into procedural steps that lead to the correct answer (Okanlawon, 2010). A review of the various teaching strategies and common learner alternative conceptions outlined in the literature is also included, as these are essential for the transformation of a teachers' comprehension into suitable formats that are understandable by learners in the TSPCK model (Mavhunga, 2012).

2.5.1. Defining Stoichiometry

Stoichiometry is defined as the 'study of quantitative aspects of chemical formulas and reactions' (Silberberg, 2006, p. 90) and involves calculations based on chemical formulas and chemical equations (Hill, Petrucci, McCreary, & Perry, 2005). A concept review of stoichiometry highlights that the mole concept, or the amount of substance containing a number of elementary units such as atoms, molecules or formula units equal to number of atoms found in twelve grams of the carbon isotope C-12, is a key concept to understanding the skills and concepts needed to master stoichiometry (Hill *et al.*, 2005; Silberberg, 2006). The mole concept, which Silberberg (2006) describes as useful as it maintains the same mass relationship between macroscopic samples and individual chemical entities, and relates the number of chemical entities to the mass of a sample of those entities, is used for a number of quantitative aspects of chemical reactions. These quantitative aspects include determining the mass percentage of elements in a compound, the empirical formula of a compound, in reaction stoichiometry to determine yields and limiting reagents and in solution stoichiometry (Gillespie, Humphreys, Baird, & Robinson, 1986; Masterton, Slowinski, & Stanitski, 1985).

2.5.2. Learner Alternative Conceptions in Stoichiometry

Understanding learners' conceptions about content concepts is one of the key aspects of the transformation of content knowledge. Therefore, a review of the literature was conducted in order to determine the common alternative conceptions learners hold regarding stoichiometry. The literature indicated that learners not only have alternative conceptions of stoichiometry concepts, but also hold alternative conceptions relating to important pre-concepts needed to successfully solve stoichiometric problems. This subsection focuses only on the alternative conceptions related to stoichiometry concepts.

In stoichiometry there are four alternative conceptions that impact on learners' ability to solve stoichiometric calculations. The first, reported by Dahsah and Coll (2007), is that learners tend to misunderstand the term amount of substance and confuse it for the mass of a substance. One of the reasons for this, which is discussed in more detail in this section of the literature review, is due to the learners' conception of the mole (Lazonby, Morris, & Waddington, 1982; Novick & Menis, 1976). Another added level of difficulty is due to the phonetic similarity between terms like mole and molecule (Novick & Menis, 1976). The second is that reactants need to be present in the stoichiometric ratios represented by balanced

chemical equations. Huddle and Pillay (1996) found that many learners, despite been given initial masses of reactants, did not calculate the amount of substance in moles represented by the given masses. In another study in Indonesia, learners were unable to relate the volume of gases to the amount of reactants present (Agung & Schwartz, 2007). Duncan and Johnstone (1973) conducted a study on misconceptions in solution stoichiometry. They found that learners did not consider that when aqueous solutions are diluted, the volume of the solution was altered and hence the concentration, and held the misconception that the volume in solutions was constant. This is the third misconception that impacts on learners' ability to solve stoichiometric problems. The fourth misconception, involves the limiting reagent in a reaction. In the studies reviewed, the majority of the learners had difficulty understanding the concept of the limiting reagent (Chandrasegaran, Treagust, Waldrip, & Chandrasegaran, 2009; Potgieter *et al.*, 2005). Learners often assume that the substance present in the least amount is the limiting reagent (Dahsah & Coll, 2007; Huddle & Pillay, 1996). Linked to this is the idea that the reactant present with the least mass is the limiting reagent (Huddle & Pillay, 1996). In the next subsection, teaching strategies to develop stoichiometry concepts is described. These misconceptions often prevent students from being able to solve stoichiometric problems (Dahsah & Coll, 2007).

2.5.3. Conceptual Teaching Strategies for Teaching Stoichiometry

The previous subsection outlined learner alternative conceptions that impact on learners' ability to solve stoichiometric problems. It has been found that learners can solve problems relating to reaction stoichiometry by relying on algorithmic approaches without the necessary conceptual understanding (Agung & Schwartz, 2007; Dahsah & Coll, 2007). Competence in algorithmic problem solving has been found to be independent of competence in conceptual questions (Gauchon & Méheut, 2007; Stamovlasis, Tsaparlis, Kamilatos, Papaoikonomou, & Zarotiadou, 2004, 2005). Teaching strategies that focus on rote learning result in learners being unable to build holistic descriptions of content or reorganise new content by relating it to their prior knowledge (BouJaoude & Barakat, 2000). A number of studies have focused on how learners solve stoichiometric problems (e.g. Schmidt, 1994, 1997; Schmidt & Jignéus, 2003; Tóth & Sebestyén, 2009). All of these studies highlight that learners tend to utilise algorithmic approaches instead of developing conceptual understanding. Developing conceptual understanding is essential since alternative conceptions interfere with future learning, making it difficult for learners to make links between science concepts (Canpolat,

Pınarbaşı, Bayrakçeken, & Geban, 2006). Therefore, as described in the introduction of this thesis, if learners do not have the necessary conceptual understanding in stoichiometry, they will have trouble understanding more advanced topics, such as acid-base reactions and chemical equilibrium (Canpolat *et al.*, 2006; Okanlawon, 2010).

Teaching strategies should therefore focus on conceptual change, as one of the components of the transformation of content knowledge outlined in the theoretical framework is knowledge of students' prior knowledge, including alternative conceptions. The conceptual change approach starts with the premise that learners hold deeply rooted conceptions that are inconsistent with science views (Duit & Treagust, 2003). These alternative conceptions were described in the previous subsection. A large body of research exists regarding conceptual change. Mackay and Hobden (2012) outline four teaching strategies that facilitate conceptual change, described by Baser (2006, in Mackay & Hobden, 2012). These four strategies include cognitive conflict, conceptual ecology, conceptual progression and conceptual appreciation. However, Linder (1993) argued that the conceptual change depiction of learning should be extended to include conceptual fitting and acknowledges the importance of learning science content that is embedded in learning environments that include the affective domain.

According to Dahsah and Coll (2007), the main aim of teaching stoichiometry should be to develop learners' understanding of the underlying concepts in order to solve numerical problems. An important aim of science instruction should also be to develop interest in science (Hassan, 2008) since such affective factors play an important role in conceptual change (Duit & Treagust, 2003), which possibly is not happening in the teaching of stoichiometry if learners find the topic uninteresting (Fach *et al.*, 2007). One such way to encourage conceptual understanding is to present content in a context from which learners can derive meaning and the significance of chemistry in everyday situations, environmental issues and industrial processes (BouJaoude & Barakat, 2003). For example, reaction stoichiometry could be taught within the contexts of ore extraction and industrial processes such as the Haber process (Evans *et al.*, 2006). Additionally, learning strategies that allow learners to logically solve problems in which they can describe the relationships of mole ratios in their own words in order to develop proportional reasoning has been found more effective than algorithmic approaches (Schmidt, 1997; Schmidt & Jignéus, 2003). It is also essential to develop problem-solving strategies that provide learners with strategies, such as using diagrams or representing macroscopic and microscopic representations to solve

problems conceptually using the 'logical method' (Fach *et al.*, 2007; Frazer & Servant, 1986a; Georgiadou & Tsaparlis, 2000). Such strategies can assist learners in successfully solving stoichiometric problems by developing their conceptual understanding.

Other effective methods for learning in stoichiometry include guided-discovery experiments, working in groups and the use of solid models for the abstract concepts involved in reaction stoichiometry (Georgiadou & Tsaparlis, 2000). According to Canpolat *et al.* (2006), there is mounting evidence that models play an important role in facilitating student learning. If the teaching context does not allow for a guided experiment approach, demonstrations can be used to help students move towards conceptual change (Canpolat *et al.*, 2006). Demonstrations that are set up to challenge learners' existing conceptual understandings can facilitate the construction of new personal meanings from pre-existing ideas if learners are given the opportunity to reflect on the ideas they express and engage in collaborative dialogue.

2.5.4. The Challenges when Teaching Stoichiometric Content

As has been mentioned, the mole concept is central to all aspects of stoichiometry described above in Section 2.5.1 and yet, in chemistry, it is one of the concepts described by authors as 'muddlesome' or 'dreaded' that give learners the most trouble (Johnstone, 2000; Lazonby *et al.*, 1982). Learning chemistry is viewed as challenging since its explanatory power lies with entities and processes occurring at a submicroscopic scale - the scale of atoms, molecules and ions - but learners make observations, including measurements, at a macroscopic level and the mole concept is required to make the connection between these two levels (Evans *et al.*, 2008). A possible reason for this difficulty experienced by learners is that they do not realise that they are expected to learn explanations for chemical phenomena that have layers of complexity, and that to understand chemistry they need to move between the macroscopic observations of the behaviour of substances, interpret these observations in terms of the unseen submicroscopic level and record these in some representational language or notation (Bond-Robinson, 2005; Johnstone, 2000). According to Johnstone (2000), this is the weakness of chemistry when trying to teach it. In addition, mathematical modelling contributes to the difficulties learners face in stoichiometry (Evans *et al.*, 2008; Yaron, Leinhardt, & Karabinos, 2004). Since learner difficulties in stoichiometry are often also linked to their conceptions of the mole, which in many cases mirror their teachers'

conception of the mole (Lazonby *et al.*, 1982; Tullberg, Strömdahl, & Lybeck, 1994), it is essential to ensure that the challenges associated with the levels of explanation in chemistry and mathematical modelling are not confounded by incorrectly conceptualising the mole. In the subsection that follows, the various conceptions of the mole will be described and the issues relating to its conception by teachers will be discussed.

2.5.5. Teachers' Conception of the Mole

The mole is defined as the amount of substance of specified chemical formula which contains as many elementary entities as there are carbon atoms in 0.012 kg of carbon-12 (Allsop, 1977; Furio, Azcona, Guisasola, & Ratcliffe, 2000). The elementary entities need to be specified and may be atoms, molecules, ions, electrons or other entities (Kolb, 1978). This definition is the definition provided by the *International Union of Pure and Applied Chemistry* for the mole, as one of the seven fundamental physical quantities, or basic units, in the SI system for measuring the amount of substance (Furio *et al.*, 2000; Kolb, 1978). The SI units include a small number of base units, from which others are derived that are agreed on internationally and recommended for use throughout science, technology and commerce (Taylor & Thompson, 2008). The various conceptions teachers have of the mole, are linked to the socio-historical use of the term 'mole' (Furio *et al.*, 2000). In the scientific community, there is a debate about aspects related to the mole (e.g. Aleksandrov, 1989; Milton & Mills, 2009). According to Nelson (2013), surveys of educators have revealed that many do not have a proper understanding of it. Due to this conceptual uncertainty it distorts an integrated learning approach for learners (Strömdahl, 1996).

Strömdahl *et al.* (1994) divided teachers' conceptions of the mole into four categories. The approach when teaching the mole is strongly bound to the teachers' conception of the mole (Tullberg *et al.*, 1994). It was due to this that the teachers' conception of the mole was deemed an important consideration for this study. Tullberg *et al.* (1994) found that, teachers used specific teaching strategies based on their conception of the mole, and formulated this as a teaching model. Therefore it can be argued that a teachers' conception of the mole is part of their pPCK, which is a synthesis of both professional knowledge and knowledge of learning contexts (Carlson & Daehler, in press). The aspects of this teaching model based on teachers' conception of the mole are incorporated in the theoretical framework discussed in Section 2.6. The four categorizations of teachers' conception of the mole involve the definition of the

mole as an SI unit and three alternative definitions of the mole that are inconsistent with the SI definition and that pose problems when teaching the mole (Dierks, 1981; Strömdahl *et al.*, 1994).

The first category of teachers' conception of the mole is that as a portion of substance. According to Strömdahl *et al.* (1994), teachers who conceptualise the mole in this way consider one mole to be a physical, concrete portion of a substance that has the property of being able to react chemically with other substances in whole value ratios. In this category of conceptualisation, the teachers' concept of the mole has nothing to do with physical quantities or units. This conceptualisation is linked to the 'equivalence method' for solving stoichiometric problems (Frazer & Servant, 1986a), which is still used today, specifically for titrations (Frazer & Servant, 1986b).

The second category of teachers' conception of the mole is as an elementary entity of specific mass (Strömdahl *et al.*, 1994). Teachers who conceptualise the mole in this way use the term mole synonymously with terms such as gram-atomic weight, gram-molecule weight and gram-formula weight, with one mole being considered as a unit of mass (Strömdahl *et al.*, 1994).

In the third category of conception, the mole is viewed as a quantity that is equal to Avogadro's number (Strömdahl *et al.*, 1994). In this category, one mole is comparable to numbers such as one dozen since it is conceptualised as a number that is equal to Avogadro's constant; teachers with this conceptualisation consider the number of moles as a pure number (Strömdahl *et al.*, 1994; Tullberg *et al.*, 1994). According to Nelson (1991), many teachers think of the mole as a counting unit and present it in this manner. However, the problem with this conceptualisation of the mole as a counting unit is that a number cannot be the unit for a measurable physical quantity (Aleksandrov, 1989; Dierks, 1981).

The fourth category of the conceptualisation of the mole, which is consistent with the SI definition, is that the mole is a unit of the physical quantity amount of substance (Strömdahl *et al.*, 1994). Within the conceptualisation of the mole that is consistent with the SI definition, the related concepts of mass, volume of gases and number of particles, used in teaching quantitative aspects of chemical change, are taught as functional mathematical relationships using proportionality to the amount of substance in terms of an elementary entity (Strömdahl *et al.*, 1994; Tullberg *et al.*, 1994). Within this framework, there is a need to clearly

distinguish between the amount of substance (n), mass (m), volume (V) and number of elementary entities (N) (Furio *et al.*, 2000). Secondly, the functional relations of the amount of substance with the quantities of mass, volume and number of elementary entities through operative expressions and various proportionality constants, such as molar mass (M), molar volume (V_m) and Avogadro's constant (N_A) respectively need to be highlighted (Furio *et al.*, 2000; Strömdahl *et al.*, 1994). These operative functions are shown in Figure 2.1. Within this framework, the term molar mass can be used unambiguously as the mass of a substance, which is equivalent to a mole of that substance (Ainley, 1991). This fourth conceptualisation represents the factual content knowledge related to the mole.

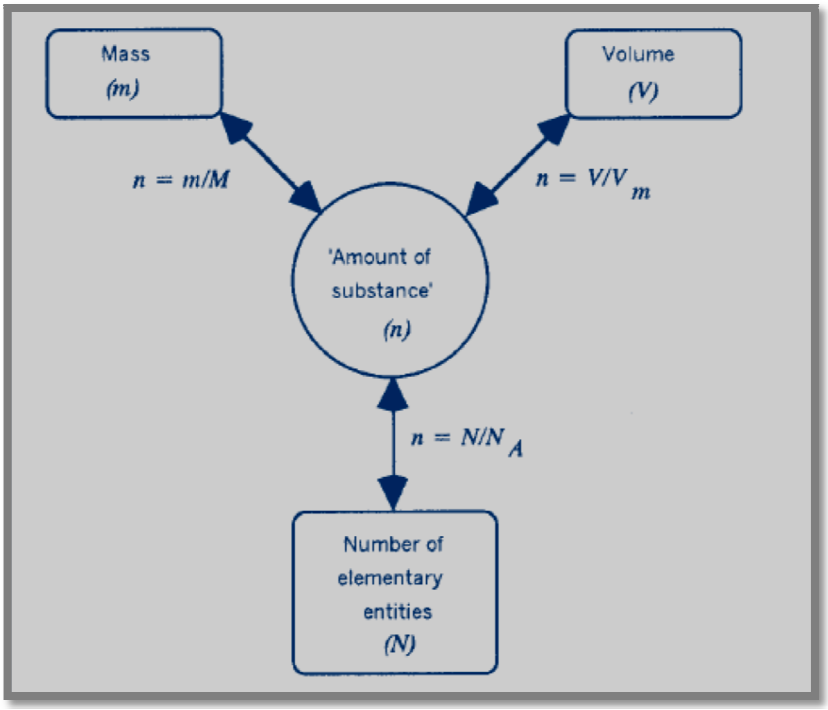


Figure 2.1: The amount of substance in relation to the quantities mass, volume and number of elementary entities (Furio *et al.*, 2000)

In order to ensure that learners develop a conception of the mole that is scientifically accurate, which has become a unifying method for measuring the amount of substance when teaching quantitative aspects of chemistry, it is essential that the SI approach is used from the outset (Lazonby *et al.*, 1982; Nelson, 1991). Central to this approach are the operative expressions that show the mathematical relationships between amount of substance, mass, volume of gases and number of entities shown in Figure 2.1. However, Allsop (1977) argues that the mole concept itself should be introduced as the relationship between the amount of substance and number of particles. Dierks (1981) explains that in order for learners to successfully cope with the mathematics involved in stoichiometric calculations, it is essential

to begin with the concept of number since it is important to move from the learner's existing knowledge to the concepts a teacher hopes to teach. This conception of the mole, adopted for this study, integrated the SI definition of the mole as the unit for the amount of substance and the analogy of the mole as a counting unit from a scientific point of view is problematic (Aleksandrov, 1989). An understanding of the problems associated with the construction of this concept, would indicate high grade knowledge of the concepts and theories of the discipline of chemistry (Furio *et al.*, 2000). The dilemmas associated with this conceptualisation of the mole as an SI unit and counting unit needs to be recognised by teachers and effectively managed (Geddis & Wood, 1997). This conceptualisation was an important aspect for both the design of the instrument (Malcolm, 2015) and for the Learning Study. A more detailed account of the conceptualisation of the mole related to the instrument design described in Chapter 4 is provided in Appendix 4. From the reviewed literature various ideas were drawn together: teacher knowledge, specifically PCK which has been described as topic-specific (Park & Chen, 2012), the TSPCK model (Mavhunga, 2012) and the teaching model for teaching stoichiometry (Tullberg *et al.*, 1994) for the theoretical framework of this study. This is outlined in the next section of this chapter.

2.6. Theoretical Framework

Teaching and learning are complex processes and are dilemma-based (Gess-Newsome, 2015; Loughran, 2010). Teachers require a knowledge base to draw from when teaching (Corrigan *et al.*, 2011). The lens through which teacher knowledge and teaching will be investigated within this study is PCK. The reason for this is that, as a form of teacher knowledge, PCK has the potential to describe teacher knowledge more carefully (Gess-Newsome, 2015) whereas practical knowledge is more subjective as it develops through personal experience and is highly context-dependant (Field & Latta, 2001; Lunenberg & Korthagen, 2009). In this section the theoretical framework for this study is outlined. Firstly, it is placed within the categories of teacher knowledge, drawn up at the first PCK summit held in Colorado (Gess-Newsome, 2015). Secondly, the model of topic-specific PCK developed by Mavhunga (2012) is located within this model as this construct was explicitly used designing the instruments to measure teacher knowledge in the topic of stoichiometry. Thirdly, the model for teacher thought (Clark & Peterson, 1986) is used as a heuristic tool to link teacher knowledge and classroom practice or enactment. Since teachers' conception of the mole influences the way teachers approach teaching stoichiometry the teaching model developed by Tullberg *et al.*

(1994) is linked to aspects of the TSPCK model, Finally, since lesson planning is a key feature of engaging in the practice of teaching (Carlson & Daehler, in press) the lesson elements for effective lesson planning are linked the model of teacher professional knowledge. Each of these aspects related to the theoretical framework of this study are outlined before drawing them together as a single framework that guided this study.

In Chapter 1 it was mentioned that since the initial introduction of PCK by Shulman various models for PCK were developed. The various models of PCK raised questions relating to its nature as a form of knowledge, or as a skill, or both, whether it is personal or canonical, that is held by a community, and if it can be measured separately from the act of teaching (Gess-Newsome, 2015). From the discussions at the PCK summit, PCK was placed within a framework for teacher knowledge and skills, and in essence decoupled personal knowledge from professional knowledge. This professional knowledge component for particular topics is collective[4] PCK (Garritz, 2015; Gess-Newsome, 2015; Rollnick & Mavhunga, 2015). For this study, the focus is on the aspect of measuring this professional knowledge, or cPCK, and investigating how it is translated in the act of teaching as enacted PCK.

The model of teacher professional knowledge and skill, or TPK&S, that was drawn up at the 2012 PCK summit in Colorado, takes cognisance of previous models (Gess-Newsome, 2015). One of the aims of the summit was to place the various models of PCK on a continuum to allow for extant research, such as that using the topic-specific PCK model, to be situated within the framework of teacher knowledge and skills. Since this model, described as a consensus model for studying PCK, was drawn up from researchers in the field, it forms the theoretical basis for advancing research in PCK (Carlson, Stokes, Helms, Gess-Newsome, & Gardner, 2015). This is the key reason this model forms the basis of the theoretical framework of this study. In this model (see Figure 2.2), five knowledge domains, including curricular knowledge, content knowledge, pedagogical knowledge, assessment knowledge and knowledge of students, described as the generic professional knowledge bases of teachers (Gess-Newsome, 2015), contribute to the development of topic-specific professional knowledge, or TSPK. TSPK in turn influences teachers' knowledge in these five domains. The model for teacher professional knowledge and skill is shown in Figure 2.2 on the next page.

[4] Collective PCK was previously referred to as canonical PCK.

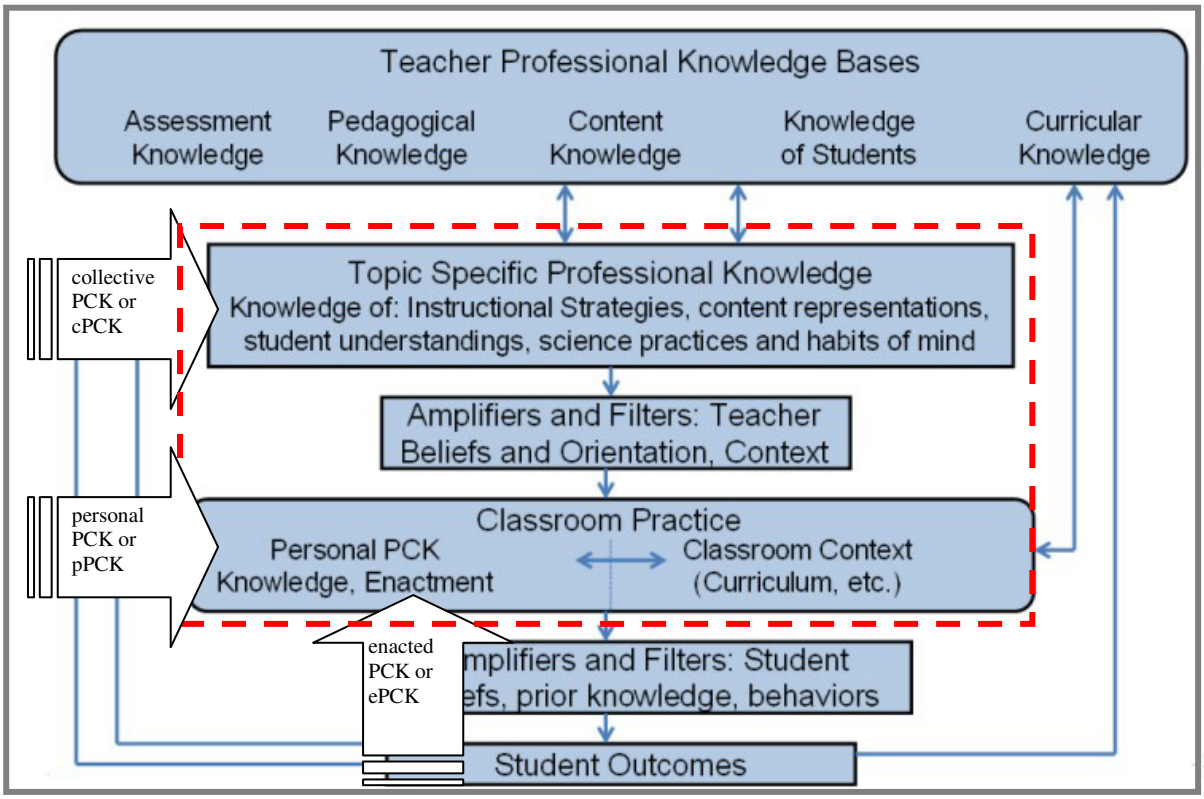


Figure 2.2: The TPK&S model including PCK derived at the PCK Summit in Colorado (Gess-Newsome, 2015)

TSPK, which explicitly emphasises that the content for teaching occurs at a topic level, includes knowledge of instructional strategies, content representations, student understandings, science practices and habits of mind (Gess-Newsome, 2015). Many of these components contribute to the transformation of content knowledge (Geddis & Wood, 1997) or are manifestations of teachers' knowledge (Davidowitz & Rollnick, 2011). TSPK is both amplified and filtered by teachers' beliefs and orientations, and context. In the Magnusson *et al*. model (1999), orientation towards science teaching was one of the components of PCK as this played a central role in the decision-making of the teacher in the other components related to PCK. However, such orientations or beliefs act as filters rather than as a component of PCK (Yerrick, Parke, & Nugent, 1997). Therefore, TSPK that is amplified and filtered influences classroom enactment that is, in turn, amplified and filtered by students' beliefs, prior knowledge and behaviours. This then influences student outcomes that feed back into classroom practice and TSPK. Within the TPK&S model, there is also a clear distinction between TSPK and classroom enactment (Gess-Newsome, 2015). For the purposes of this study, the focus is on TSPK and classroom enactment. From the second PCK summit TSPK is now referred to as collective PCK, or cPCK (see Figure 2.2) and classroom practice is referred to as enacted PCK, or ePCK (Rollnick, 2018). Teachers' draw on their personal

PCK, or pPCK when teaching and this is observed as ePCK (Berry, Nilsson, Van Driel, & Carlson, 2017; Rollnick, 2018).

The topic-specific model of PCK focuses particularly on the cPCK component within the TPK&S model (Rollnick & Mavhunga, 2015). This model can still be used in describing and measuring cPCK for a particular topic since the TPK&S model was developed to allow 'extant research to be situated within the model' (Gess-Newsome, 2015, p. 30). The TSPCK model therefore provides the mechanism for the transformation of content knowledge for a particular topic, that can be described and used to construct measures and tested to determine what teachers know (Gess-Newsome, 2015). Placed within the cPCK component of the model above, is knowledge about teaching particular topics that is required to transform content knowledge for a particular topic into classroom practice or enactment (Ball *et al.*, 2008; Rollnick & Mavhunga, 2015). It is this knowledge that teachers require in order to have the necessary flexibility to teach and learn new content. This knowledge goes beyond merely the transmission of information; there has to be a conscious combination of the knowledge domains of content knowledge, knowledge of pedagogical and contextual issues when teaching (Gess-Newsome, 1999a; Rollnick *et al.*, 2008).

Two common features appeared in all previous models of PCK (Park *et al.*, 2011; C. Smith, Blake, Kelly, Gray, McKie, & Mcnally, 2011). The first of these components is knowledge of instructional strategies that incorporate representations of subject matter; secondly are learner conceptions regarding the subject matter (Park *et al.*, 2011) which incorporates both knowledge of and understanding of specific learning difficulties that are included in the TSPK or cPCK component of the TPK&S model (see Figure 2.2). It is within these two components that effective pedagogical transformation of content knowledge can occur. Effective pedagogical transformation produces end products, such as representations of the subject matter and conceptual instructional strategies, interaction with learners, explanations, assessment and curricular saliency and these transformations are observable manifestations in classroom practice (Davidowitz & Rollnick, 2011). These manifestations, which are based on teachers' knowledge, are developed through experience when teachers teach particular concepts and knowledge therefore develops for particular topics that are therefore unique to the topics, or topic-specific (Van Driel, De Jong, & Verloop, 2002). Therefore, the model of topic-specific PCK is viewed as the mechanism for the measurement and development of teachers' cPCK and forms part of the theoretical framework for this study.

TSPCK has been defined as 'a theoretical construct referring to the capability needed to transform teachers' own comprehension of a given topic into formats that are suitable for teaching' (Mavhunga, 2012, p. 20). The TSPCK model developed by Mavhunga (2012) is presented in Figure 2.3 on the next page. Within this model, a teachers' PCK is an integration of various knowledge domains within the teachers' repertoire and includes knowledge of context, knowledge of learners, content knowledge (referred to as subject matter knowledge) and pedagogical knowledge, as in the TPK&S model (see Figure 2.2). These knowledge domains are influenced by the teacher and student-orientated beliefs, and these beliefs are, in turn, influenced by the various knowledge domains, in the same way as they filter and amplify knowledge and practice in the TPK&S model. These beliefs, according to Magnusson *et al*. (1999) guide instructional decisions. Within the TSPCK model, there is a unilateral influence of subject matter knowledge, or CK, on TSPCK. Hence the belief that good CK is a prerequisite for the development of PCK (Kind, 2009b), is a central understanding of this model (Mavhunga, 2012). The possible influence of the knowledge bases of knowledge of students and pedagogical knowledge on TSPCK is acknowledged by the unidirectional arrows (faint lines in Figure 2.3) in the model because of the relatedness of these knowledge domains to two of the specific content components, namely, students' prior knowledge and conceptual teaching strategies (Mavhunga, 2012).

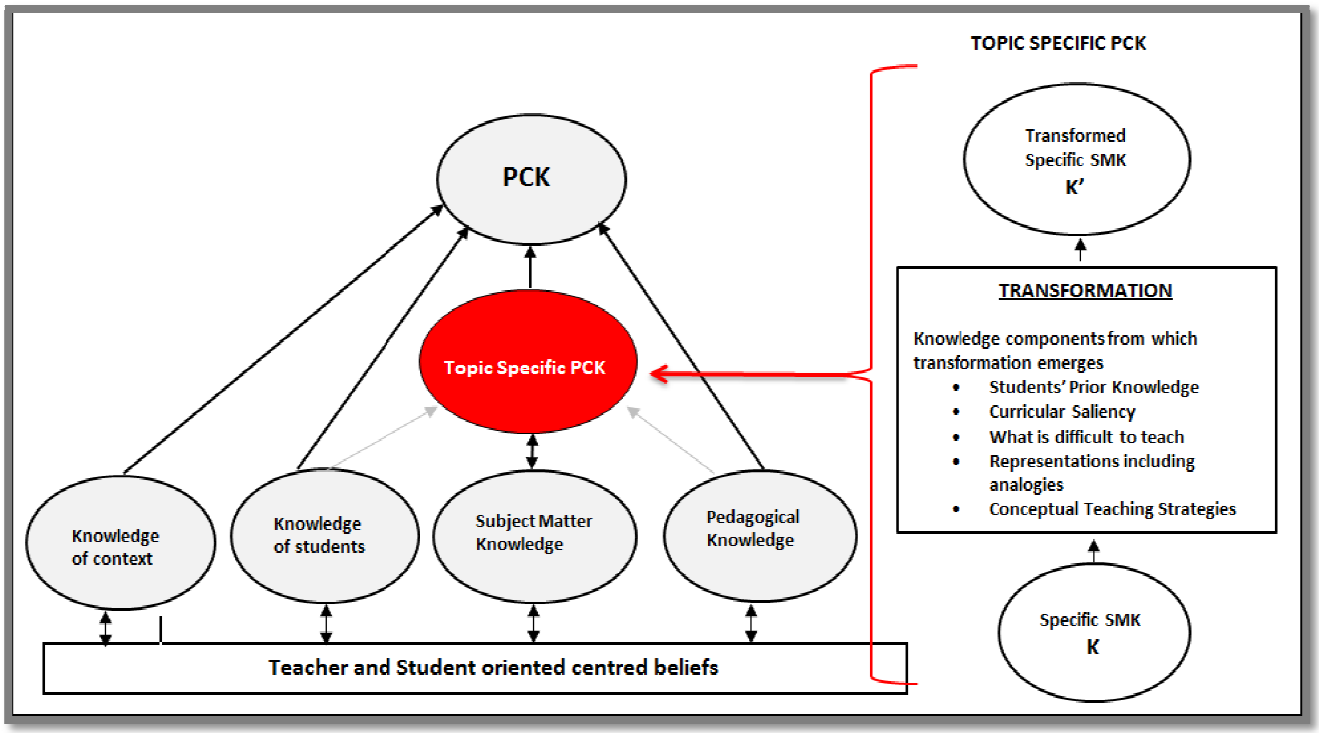


Figure 2.3: Model of Topic-specific PCK (Mavhunga, 2012)

The components of TSPCK within this model are based on the idea of the transformation of teachers' understanding of subject matter, or CK, into forms that are accessible to learners. This transformation is described as the result of teachers processing their comprehension of a specific topic through the five different components (Geddis & Wood, 1997; Mavhunga, 2012). The five components of TSPCK (see Figure 2.3) are described by Mavhunga (2012) and are outlined briefly here. The first component in the model is that of *learners' prior knowledge* about a topic and includes alternative conceptions about the topic and learning difficulties. The second component deals with a range of dissections of a topic like decisions relating to what concepts are core and which are peripheral; what pre-concepts are to be in place prior to teaching; which concepts are important in teaching the topic and their sequencing when teaching the topic, referred to as *curricular saliency*. The third component, namely *what makes it easy or difficult to teach the topic*, relates to learning difficulties but also contextual factors that could hinder learners grasping the topic. The fourth component, *representations*, refer to all forms of representations such as graphs, pictures, analogies and models to help learners understand the topic. Within the context of chemistry, macroscopic, sub-microscopic and symbolic representations are essential for developing conceptual understanding (Bond-Robinson, 2005). Finally, the fifth component, *conceptual teaching strategies* are the conceptual strategies based on the content of the topic. This includes knowing what specific conceptual discussions and/or actions to bring to the teaching of these concepts in order to expand on an area of difficulty. Conceptual teaching strategies go beyond the use of just pedagogical strategies and are informed considerations of the conceptual architecture towards mediating learning in the topic. They refer to the confrontation of potential confusion and alternative conceptions through the use of a combination of conceptual principles and rules for a particular topic.

The TSPCK model, developed from the tailored model (Davidowitz & Rollnick, 2011), does not include the manifestations of PCK (Mavhunga, 2012). Mavhunga (2012) explains that this was done since observable practice was not part of the study for which the model was developed. Rather, it focused on the comprehension of content knowledge for a given topic, and the competencies that enable the transformation of the topic as teachers reason through the intended teaching. Evidence of this would be seen at the level of planning for teaching. However, since this study aims at investigating practice, or enacted PCK, the manifestations of the TSPCK components in teaching will need to be identified and mapped to see the extent

to which they are integrated (Park & Chen, 2012). The transformation aspect of Shulman's pedagogical reasoning is an important aspect of the planning for teaching that represents the intersection between pedagogy and content (Bishop & Denley, 2007; Mavhunga, 2012). In practice, the aspects related to instruction, evaluation and reflection to develop new comprehension in the cyclical process of pedagogical reasoning (Shulman, 1987) link TSPK with classroom practice or enactment in the TPK&S model (see Figure 2.2). In order to link both the planning for teaching and classroom enactment, to understand the how and why the teaching process unfolds, the model for teacher thought and action shown in Figure 2.4 will be employed as a heuristic device to do this (Clark & Peterson, 1986).

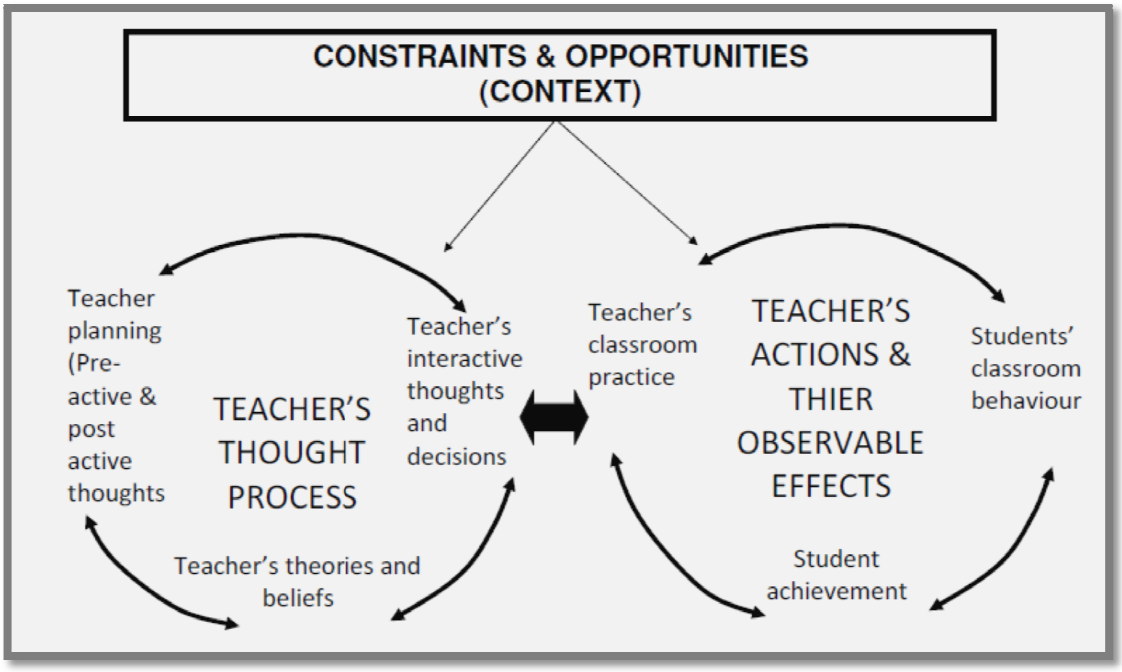


Figure 2.4: Model of teacher thought and action (Clark & Peterson, 1986)

Teacher thought and action are two important domains in teaching influenced by constraints and opportunities related to the context in which teaching happens (Clark & Peterson, 1986). Context is a filter between TSPK and classroom practice and enactment in the TPK&S model and the classroom context is a key aspect in the realm of classroom practice (see Figure 2.2). The domain of the teachers' thought process falls within the teachers' knowledge as represented in the TPK&S model, both at the level of TSPK, in terms of teacher planning, and interactive thoughts in practice. In terms of teacher planning, a teacher's thought processes includes post active thought, or reflection. For this study, the post active thoughts, particularly for the Learning Study, teachers reflect on the lesson collaboratively in order to improve the lesson and enhance student learning (Nilsson, 2014). Teacher beliefs act as a filter and amplifier in this process (Gess-Newsome, 2015). The second domain is that of

teachers' action, classroom enactment which is influenced by the teachers' professional knowledge bases, including knowledge of pedagogy and is observable as manifestations (Davidowitz & Rollnick, 2011), student behaviour and student achievement. However, for this study, the focus is on the planning and teacher knowledge used in the act of teaching the topic of stoichiometry (Gess-Newsome, 2015) but cognisance is taken of how student achievement and classroom behaviour influence teacher actions.

The TPK&S model (Gess-Newsome, 2015) was used in this study as framework for investigating teacher knowledge. However, the TSPCK model (Mavhunga, 2012) provides the vehicle for the transformation of content knowledge for a topic and Rollnick and Mavhunga (2015) equate it with TSPK, now referred to as cPCK (Berry *et al.*, 2017; Rollnick, 2018) in the TPK&S model. Therefore for this study, the level of TSPK has been replaced with TSPCK model for the theoretical framework (see Figure 2.5) to investigate not only TSPCK development but the translation of TSPCK in planning to teach into enacted PCK, or ePCK which is discussed in Chapter 6 and Chapter 7 respectively. The components of learner prior knowledge and what is difficult to teach are placed first in this level since all conceptual teaching strategies begin with learner difficulties (Mavhunga, 2015). The conceptual teaching strategy component is in last place in this level (see Figure 2.5) since it subsumes all the other components which work together to create a conceptual teaching strategy (Rollnick & Mavhunga, 2014).

The teaching model for teaching stoichiometry, based on teacher conception of the mole is used to broaden the component of curricular saliency as shown in Figure 2.5. This has been done based on the description of the model described by Tullberg *et al.* (1994), since it is similar to aspects of curricular saliency (see Figure 2.5). These similarities are outlined below.

According to Tullberg *et al.* (1994), teachers' approach to teaching stoichiometry is based on their conception of the mole, on which they often structure their teaching sequence. Based on this conception, teachers teach stoichiometry in a teaching model (Tullberg *et al.*, 1994). This teaching model comprises five distinct phases or subordinates. The first involves a teacher's own conceptions and knowledge of the mole which has been described previously in this chapter, and therefore influences the teaching approach. The second subordinate involves the strategic long term plan for teaching the mole, essentially in paving the way by identifying which core concepts are necessary prerequisites before introducing the mole. The third

subordinate is described as the tacit, or short-term plan for teaching the mole. This includes motivating to learners why it is necessary to learn about the mole and why chemists need to use it. The fourth, described as tacit realisation includes defining the mole and relating it to the relevant concepts by linking the macroscopic view of matter with the submicroscopic or particle view. The fifth and final subordinate is the application of the mole concept and incorporates the use of the mole in stoichiometric calculations. These subordinates described by Tullberg *et al.* (1994) link with the dissections of the topic described by Mavhunga (2012) as related to curricular saliency. These links are summarised in Table 2.1 and represented graphically in Figure 2.5 on the next page.

Table 2.1: The links between the teaching model subordinates and curricular saliency

Teaching Model Subordinate (Tullberg *et al.*, 1994)	Aspect of Curricular Saliency (Mavhunga, 2012)
Sub-ordinate 2: Strategic/long term plan Pre-requisite concepts that need to be taught before introducing the mole	Knowing which concepts need to be in place before teaching a topic
Sub-ordinate 3: Tactic/short term plan Motivating the use of the mole to students	Knowing why the topic is important (conceptual scaffolding and application to everyday life.
Sub-ordinate 4: Tacit realization Defining the mole, relating it to relevant concepts and linking macroscopic view of matter with particle view	Structural overview of the topic and identifying the big ideas and develop meaning
Sub-ordinate 5: Application of mole concept and consolidating new knowledge	Structural overview of the topic, identifying and sequencing the big ideas and develop meaning

Teachers' conception of the mole and the teaching model played a role in determining the baseline quality of teachers' TSPCK in stoichiometry for this study, which is reported on in Chapter 4, specifically due to the claim that teacher instructional strategies are influenced by their conception of the mole. The teaching model subordinates therefore suggest a plan for teaching stoichiometry and hence the link to the elements for planning effective lessons in the theoretical framework of this study.

Stender *et al.* (2017) argue that teachers use their cPCK to develop lesson plans, and with experience and reflection, these become committed to memory as teaching scripts. In effective lesson planning, there are generic instructional processes, or instructional elements in the lessons. Hunter and Russell (1976) identified seven elements to be considered when planning a lesson that are considered research-validated practices used to promote student learning (Wolfe, 1987). All seven elements do not need to be present in a lesson nor be sequenced in order in a lesson (Wolfe, 1987).

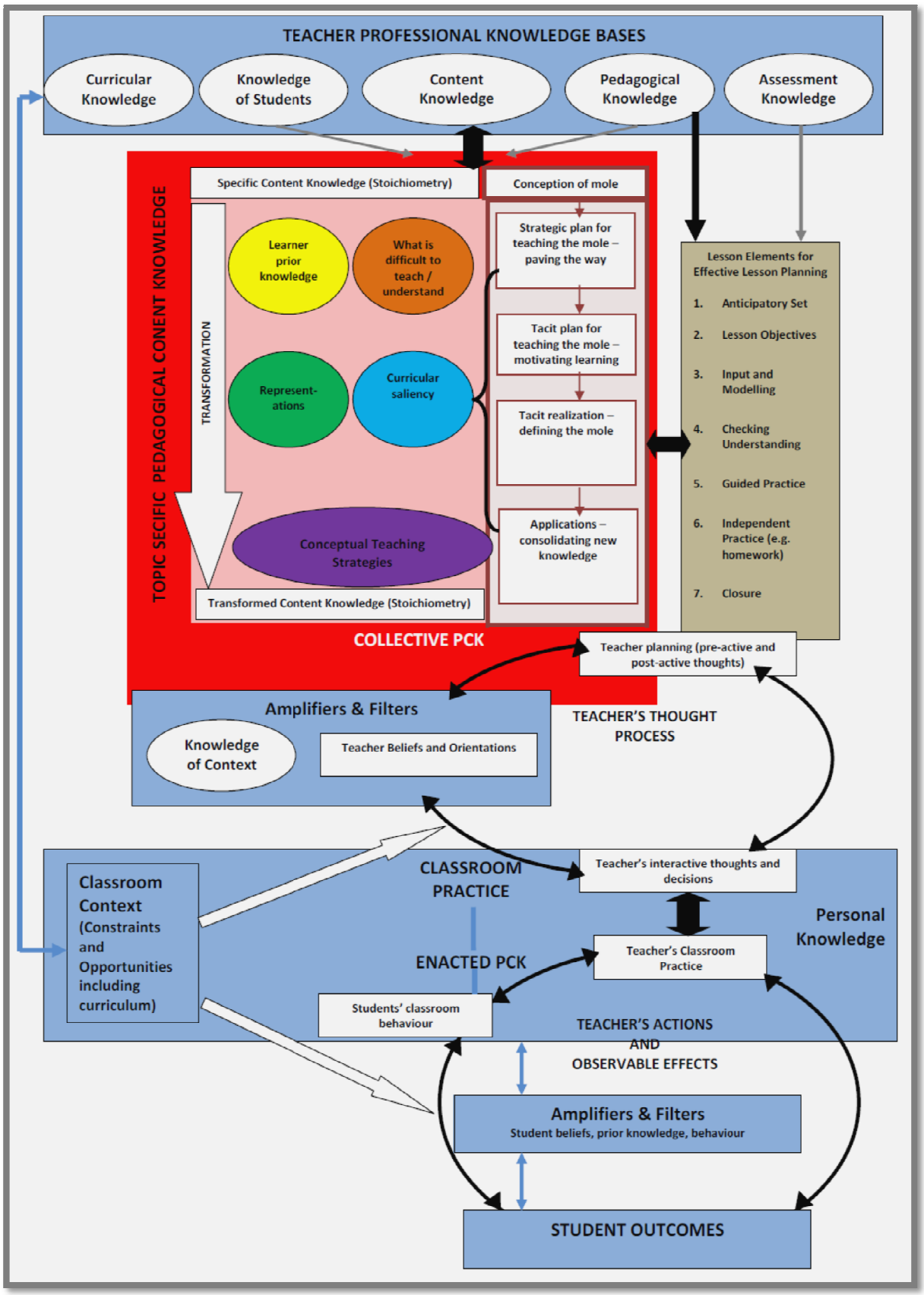


Figure 2.5: Reworked TPK&S Model including TSPCK and teaching model for teaching stoichiometry

The elements present in the lessons include: anticipatory set, objectives, input, checking for understanding, guided practice, independent practice and closure (Hunter & Russell, 1976). The anticipatory set includes motivating learning and outlining the importance of learning the concept or including a focus on learner prior knowledge. Stating lesson objectives is the second element. Input, which is the third lesson element includes teaching the main concepts, The fourth element, checking for understanding, includes interpreting student reactions and frequent formative feedback, such as responding to student questions; this can provide evidence of a teacher's on-site PCK (Chan & Yung, 2015). The fifth and sixth elements include providing students with guided practice and independent practice such as homework. The last element, closure, includes a final summary of the lesson. Lesson planning is part of a teacher's general pedagogical knowledge and provides the link between teachers' cPCK and practical routines (Stender *et al.*, 2017). These lesson elements were a key consideration in developing the lesson plan in the Learning Study and were used as an analytical tool for investigating lesson enactment which is reported on in Chapter 7.

The model for teacher thought and action has been rotated to link the filters and amplifiers in the TPK&S model and classroom practice (see Figure 2.5). However, this model is only employed as a heuristic device to link teacher thinking with classroom practice (Clark & Peterson, 1986). The ways in which this was done in this study are outlined in the next chapter. The elements for effective planning are drawn from teachers' general pedagogical knowledge and, to some extent, assessment knowledge (Gess-Newsome, 2015), and linked to the model of teacher thoughts and actions which includes planning (Clark & Peterson, 1986). The arrow between the lesson elements and the TSPCK block indicates a link between teachers' cPCK and practical routines (Stender *et al.*, 2017) in order to investigate enacted TSPCK.

2.7. Summary

This chapter has provided a review of the literature in order to provide a picture of teacher knowledge, including PCK and effective teaching, since PCK is considered to be topic-specific (Park & Chen, 2012). This chapter has also provided an outline of the theoretical framework for teacher knowledge. The focus of this study is on the topic-specific level through the TSPCK model and the link between TSPCK and classroom enactment. The transformation of CK for a particular topic is a key aspect of the TSPCK model. Central to

the topic of stoichiometry is the mole, which is poorly conceptualised by the majority of teachers. Teaching approaches to teaching stoichiometry are therefore linked to teachers' conception of the mole. In the chapter that follows, the research methodology and methods to investigate the impact of teachers' collaboration, in a Professional Learning Community participating in a Learning Study on their TSPCK development and classroom enactment, or enacted TSPCK are described in detail.

CHAPTER THREE

Research Methodology

This chapter describes the research design and methodology investigating the impact of a Learning Study on the development of experienced teachers' topic-specific PCK and the impact on enacted TSPCK in the classroom. Firstly, the research paradigm, research methodology and research strategy are discussed. Secondly, the data collection is described. Since this study was conducted in two phases, and each phase used a mixed methods approach, the qualitative and quantitative data collection methods are described. The instruments used in data collection for this study are also described. The participants are described, including the target population and the sampling for both Phase I and Phase II of this study. This includes a brief biography of the teacher participants and the expert team members who formed the team of the Professional Learning Community involved in the Learning Study. Since this study also aimed at investigating the extent that the collective topic-specific PCK is enacted in the classroom through participation in a Learning Study, the equivalence of the Learning Study group of teachers and a comparison group is established. A brief outline of the Learning Study as the treatment used is provided. Data analysis techniques are described for both Phase I and Phase II of this study. There is also an overview of how classroom enactment was analysed. Finally, issues relating to validity and credibility, ethical considerations and limitations of the study are presented.

3.1. Introduction

This study set out to explore the impact of a Learning Study, a professional development intervention in which a lesson was planned collaboratively and explicitly around the components of topic-specific PCK, in the practice of experienced Physical Sciences teachers. This chapter therefore provides an overview of the research design and research strategy that was used to address the research aim. The main thrust of the research focused on teacher learning, and therefore on the practice of teaching (Mathewson Mitchell & Reid, 2017). The chapter therefore provides an outline of how classroom enactment was investigated to account for teacher learning through participation in a collaborative Professional Learning Community. Teacher learning for this study was situated in developing teachers' knowledge in the application of teaching a particular topic and this knowledge can be identified and

described (Gess-Newsome, 2015). Working therefore within this framework of teacher knowledge, teachers' TSPCK for stoichiometry needed to be described in order to construct a measure to determine what teachers knew and used as a framework for the design of the professional development intervention. Since no existing instrument existed to measure teachers' TSPCK in stoichiometry, this necessitated that the study be conducted in two phases.

The first phase required, firstly, the design of valid instruments that could be used to measure the quality of South African Physical Sciences teachers' TSPCK and CK in the topic of stoichiometry. Secondly, the validity of the instrument to measure TSPCK had to be determined in order to gauge whether the instrument could be used to measure change of knowledge before and after an intervention. Since content knowledge is considered a precursor for the development of PCK (Kind, 2009b) a CK instrument was also compiled and validated. The design and validation of these instruments is described in my M.Sc Research Report (Malcolm, 2015). These instruments therefore provided the data necessary to determine the quality of experienced practising teachers' TSPCK in stoichiometry which is reported on in this thesis.

The second phase used the findings from the first phase to inform aspects of the professional development activity such as the use of representations and the type of conceptual teaching strategies to use. During this phase the designed instrument was used to describe the change in teachers' TSPCK in stoichiometry, supported by detailed descriptions and narrative (McMillan & Schumacher, 2010), in order to account for observed change or lack thereof. The research design that was employed to investigate the impact of this collaboration on the development and enactment of TSPCK into practice was mixed methods, since both quantitative and qualitative data were collected. The collection of both qualitative and quantitative data was necessary since, as an educational researcher examining teacher knowledge and classroom enactment, there was a need for 'a large toolkit of methods and designs to address complex problems' (Creswell & Garrett, 2008, p. 321). The mixed methods design, referred to as multiphase design, is described (Creswell, 2012). Since mixed methods involves the integration of qualitative and quantitative methods, built on philosophical differences in both the structure and confirmation of knowledge (Foss & Ellefsen, 2002), the research paradigm is outlined before describing the methodology.

3.2. Research Paradigm

One of the most significant factors that shape views on research, or research paradigms, is based on epistemology (Opie, 2004). My research aims to determine the quality of teachers' TSPCK and investigate TSPCK development and enactment in the classroom through the explicit inclusion of the construct in collaborative planning in a Learning Study. Determining the quality of teachers' TSPCK and content knowledge with the aid of instruments can provide empirical, quantitative data and hence measure teachers' TSPCK and content knowledge. So it may be assumed that my ontology is positivist, believing that knowledge cannot exist beyond that which is objectively and immediately observable (Opie, 2004).

However, teacher knowledge that influences practice is described as tacit (Gess-Newsome, 2015; Loughran, Mulhall, & Berry, 2004; Rohaan *et al.*, 2011) and is a form of knowledge that is structured within the long term memory of teachers (Gess-Newsome, 1999a). It is therefore created within the mind of individual teachers. As such, this knowledge can be said to be subjective and based on experience, which is an indication of a rationalist view of knowledge, or paradigm (Opie, 2004).

Since classroom practice is amplified and filtered by a multitude of other factors (Gess-Newsome, 2015), these factors need to be acknowledged and considered in terms of the impact on teaching practice. Therefore, this research was conducted within a pragmatist paradigm, employing mixed methods. Within this pragmatist paradigm, the philosophical approach is to use procedures that, when combined, not only help to understand the research problem, but add new perspectives to the phenomenon being investigated (Creswell, 2012; Foss & Ellefsen, 2002).

3.3. Research Design: Mixed Methods

The research design for this study is based on mixed methods research. Mixed methods research can be defined as research in which a researcher collects and analyses data, integrates findings and draws inferences from both qualitative and quantitative approaches in a study (Creswell & Tashakkori, 2007). The use of mixed methods for this study was primarily due to the tacit nature of PCK (Gess-Newsome, 2015; Loughran *et al.*, 2004) and the fact that this study aimed to not only describe TSPCK in practising teachers but explain PCK development and enactment in classroom practice (Abell, 2008). The research strategy, described in the next subsection in more detail, is a case study and necessitated a mixed methods design that Creswell (2012) refers to as a multiphase design, which is highly complex. This infers that the design builds on other basic mixed method designs, such as exploratory sequential and convergent parallel designs (Creswell, 2012). Furthermore, a multiphase design is essential since this study aims to advance the research objective of investigating the enactment of TSPCK in classroom practice by addressing a series of incremental research questions (Creswell, 2012; Rollnick & Mavhunga, 2015). Figure 3.1 on the next page provides an overview of the different phases in this multiphase mixed methods study.

Phase I was an exploratory sequential design, in which qualitative data collection was followed by quantitative data collection (Creswell, 2012) in order to design valid instruments to measure teachers' TSPCK and content knowledge in the topic of stoichiometry. This thesis reports on the measurement of the teachers' TSPCK as the design and validation of the instruments was reported on in my M.Sc Research report (Malcolm, 2015). The data collected from the instruments was analysed both qualitatively and quantitatively to build a picture of the quality of experienced Physical Sciences teachers' TSPCK (see Figure 3.1). Phase II was a convergent parallel design in which quantitative data, some of which was obtained in Phase I, and qualitative data were collected separately and merged to understand the impact of a professional development activity on the development of TSPCK and its enactment in classroom practice (see Figure 3.1). Each phase of this study is expanded on in Section 3.7.

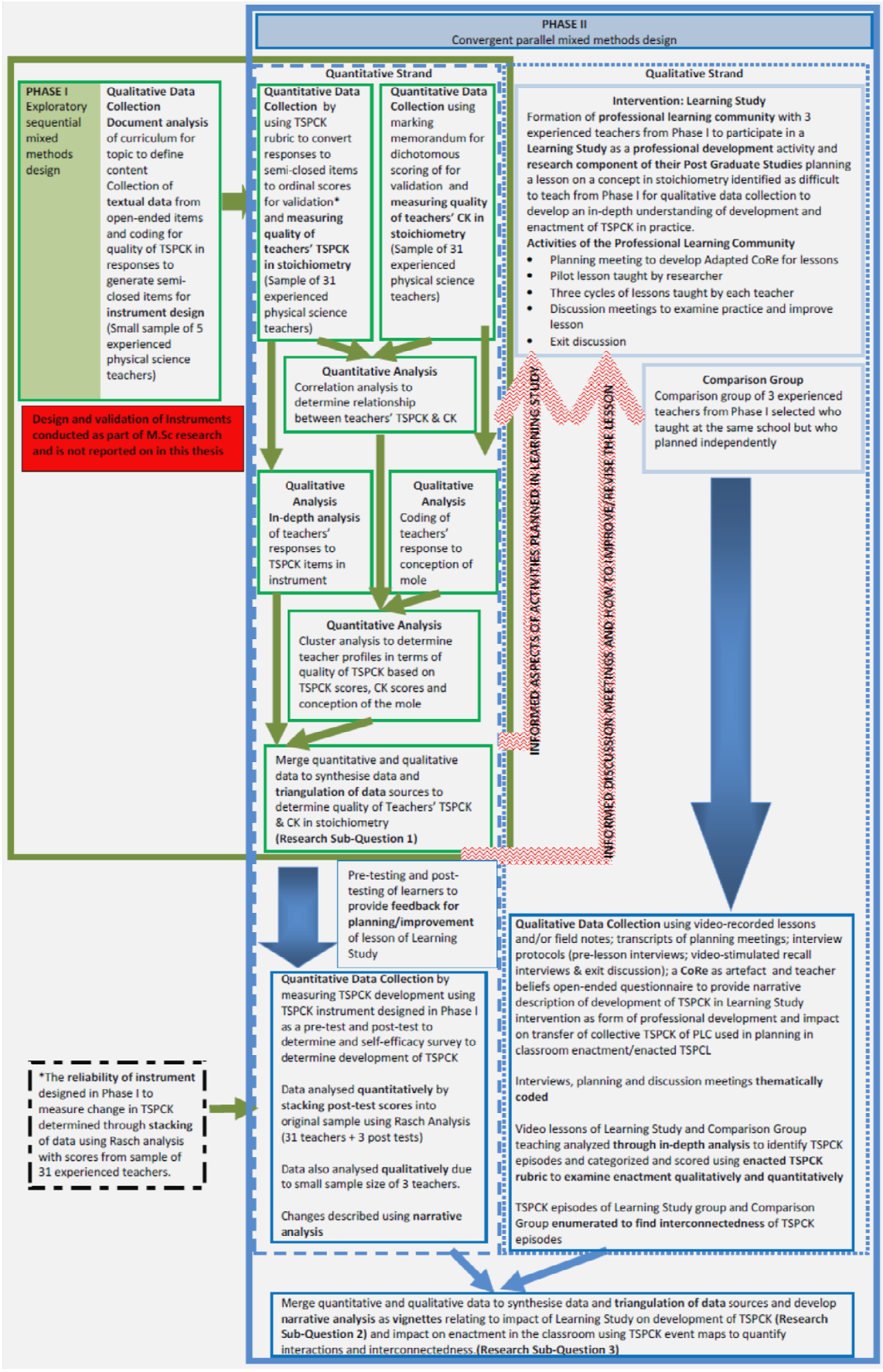


Figure 3.1: Summary of multiphase mixed methods design for this study

In order to address the first sub-question, to determine the quality of practising teachers' TSPCK and content knowledge, valid instruments for this purpose were required. However, since no existing instrument existed to measure TSPCK in stoichiometry, it was not possible to adapt an existing instrument, and hence I needed to design one for the purposes of my research. This is reported on in my M.Sc Research report (Malcolm, 2015). The reason for the use of an exploratory-sequential mixed method research design to address the first research sub-question is that the use of the textual data served a development purpose to help inform the construction of TSPCK items to score qualitatively using a rubric (Johnson, Onwuegbuzie, & Turner, 2007). Therefore, a conversion approach was also used since a TSPCK rubric was used to convert qualitative responses into quantitative scores for analysis (Onwuegbuzie & Johnson, 2006).

In order to address the second sub-question, the impact of participation in a professional development activity on TSPCK development, a convergent-parallel design was used. This sub-question was investigated in the second phase of the research, once the quality of science teachers' TSPCK in stoichiometry had been established. During this phase of the research, a convergent parallel mixed methods design was used since both quantitative and qualitative data was collected and merged (Creswell, 2012) from three experienced teachers as part of a Professional Learning Community involved in a Learning Study. Data was also collected from a comparison group of three experienced teachers teaching in the same school, but who do not plan lessons together and work independently.

A Learning Study is a collaborative process in which teachers draw from their experience and the expertise of other teachers and researchers to explore specific goals and address student needs by exploring their practice. It is a social activity and, in this context, used for professional development (Chokshi & Fernandez, 2004; Ono & Ferreira, 2010). To facilitate the planning for each lesson cycle of the Learning Study, quantitative data as part of the convergent parallel mixed methods design was used to determine student outcomes by administering conceptual diagnostic tests to students before and after the lesson was taught. This data was used only to help facilitate discussions about the lesson and inform planning for the next cycle. Any form of professional development of practising teachers is also focused on adult learners with various forms of knowledge and beliefs that builds on existing knowledge, aimed at improving practice (Starkey, Yates, Meyer, Hall, Taylor, Stevens, & Toia, 2009). As such the development of TSPCK is a complex process and simply measuring

participants' TSPCK before and after the Learning Study would not provide enough information to address the second sub-question (Creswell, 2012). The quantitative measurement of the quality of the teachers' TSPCK before and after the planning intervention, which was analysed qualitatively since only three teachers participated was unable to provide insight into reasons for any change, or lack thereof, of the quality of the teachers' TSPCK. However, the narrative qualitative strategies to capture and analyse the manifestations of their thinking in discussions in the planning phase, the enactment of the lessons and the post-lesson forum provided a more detailed account of the context of the development of the participants' TSPCK (Creswell, 2012).

Since teacher beliefs act as a filter or amplifier and impact on classroom practice (Gess-Newsome, 2015; Roehrig & Kruse, 2005), data regarding the participants' beliefs was also collected, using a qualitative descriptive method strategy. The quantitative and qualitative data from these various sources, analysed separately, was compared and related to each other to determine the convergence of data collected. In analysing the quantitative and qualitative data, equal priority was given to each, a key aspect of a mixed methods approach (McMillan & Schumacher, 2010) to determine the extent of the participants' development of TSPCK through collaborative planning.

To address the third sub-question, relating to the extent in which the collective PCK evident in the PLC is enacted in classroom practice, qualitative research strategies were employed as part of the convergent parallel mixed methods design. This is due to the fact that teaching practice was observed and therefore studied, as it occurred naturally in the classroom setting (McMillan & Schumacher, 2010). Due to the multidimensionality and unpredictability of classroom events (Chan & Yung, 2015; Doyle, 1986), the situational context in which observations occurred needed to be taken into consideration (McMillan & Schumacher, 2010). During this phase of the research, extensive data was collected from observations, field notes and audiovisual materials to identify episodes[5] of TSPCK enactment in the lesson and interviews with participating teachers to determine their reasoning and thinking when formulating responses (Creswell, 2012). To address this sub-question, the process of teaching needed to be considered and inductive reasoning needed to be employed to determine how the TSPCK evident in the PLC is enacted during practice (McMillan & Schumacher, 2010).

[5] TSPCK episodes are teaching segments where two or more components of TSPCK are identifiable.

The advantages of a mixed methods methodology is that it allowed for the study of the process as well as the outcomes (McMillan & Schumacher, 2010), in this case the impact of collaborative planning on TSPCK development and on enacted TSPCK and the design of a valid TSPCK instrument to measure teachers' TSPCK in stoichiometry. The use of mixed methods also compensated for the limitations of a single method in an attempt to enhance the credibility of findings from a single method (McMillan & Schumacher, 2010). One of the pitfalls that needed to be avoided in this study was to ensure that neither method was used superficially but that each was integrated in the data collection, analysis of data and the findings (McMillan & Schumacher, 2010). In order to highlight how an attempt was made to avoid this pitfall, a description of how qualitative and quantitative approaches were used to address each research sub-question is provided in Section 3.7.

3.4. Research Strategy: Case Study

The research strategy, or general plan for answering the research question, took the form of a collective case study since multiple cases are described and compared (Creswell, 2012). According to McMillan and Schumacher (2010), a case study is an in-depth analysis of a single entity and Creswell (2012) refers to this entity as a bounded system. According to Henning, Van Rensburg, and Smit (2004), the system may be a group of people, in this case experienced physical science teachers teaching a group of students that are bounded by set parameters. Creswell (2012) also states that the bounded system may be an event, such as teaching a planned lesson, or a process such as collaborative planning in a Learning Study. A bounded system refers specifically to the case being separated out for research in terms of time, place or some physical boundary (Creswell, 2012; Stake, 1988). In this study, the cases are separated out in terms of time since the practising teachers are teaching a lesson about the mole concept in an iterative cycle of a Learning Study. For the comparison group, the cases are separated out in terms of time, since the teachers taught lessons about the mole concept in set periods during the school day.

The cases are also separated out in terms of place, in that the teaching happens in the classroom, with the physical boundary being the school in which teaching is happening, or the Professional Learning Community participating in a Learning Study. Another feature of a case study is that it involves the intensive description and analysis of a social unit (Merriam, 1998). For this study, the social unit is constituted at two distinct levels. The first social unit

is a group of experienced practising science teachers involved in the collaborative planning and evaluation of lessons through teaching and observing them in real classrooms (Fernandez, 2005). The teachers in the comparison group were not involved in such a collaborative social group, but worked independently. This is typical of teaching which is often conducted within a state of professional isolation - in South Africa, teachers are not encouraged to share educational practices or collaborate (Botha, 2012). The second social unit is the classroom, comprising the teacher and the students interacting during a lesson (Doyle, 1986). For this study, multiple cases were studied in order to effectively address the research question, with each teacher being a case. All six cases are located within a larger context (Creswell, 2012), namely experienced practising physical science teachers with at least five years teaching experience and with high levels of content knowledge in stoichiometry. Three of these cases are located within the context of participating in a Learning Study.

The purpose of using this research strategy was to provide a descriptive narrative and in-depth understanding of the impact of professional development on teachers' TSPCK in stoichiometry and on their classroom enactment; they are therefore instrumental cases (Creswell, 2012; McMillan & Schumacher, 2010). The advantage of using this research strategy for a mixed methods research design is due to the fact that in case studies, data collection is extensive and varied (McMillan & Schumacher, 2010). For this study, data collection involved the use of specifically designed instruments to measure the quality[6] of participants' content knowledge and TSPCK in stoichiometry, classroom observations and field notes, audiovisual data, teacher interviews, teacher questionnaires and learner diagnostic tests. As a strategy, case studies allow not only for the collection of data in a controlled fashion, such as administering questionnaires and pre- and post-diagnostic instruments to students for statistical analysis but also descriptive analysis of the lessons (Henning *et al.*, 2004). Thus, multiple forms of data, both quantitative and qualitative were collected in order to provide a more complete understanding of the development of TSPCK (Creswell, 2012) and its enactment in practice through professional development.

[6] For the purposes of this study quality of teachers' TSPCK is based on the Rasch scores whereas the quality of teachers' CK is based on their scores in the CK instrument (see Mavhunga, 2012; Ndlovu, 2014).

3.5. Participants

Before the Learning Study could be conducted, it was necessary to determine the quality of experienced teachers' TSPCK in stoichiometry by designing an instrument to do so. This study was therefore conducted in two phases as described in the previous section. This section provides a description of the participants, firstly for Phase I, the instrument design, where the teachers' responses were used to determine the baseline quality of teachers' TSPCK in stoichiometry. Secondly, the members of the Professional Learning Community, which included three participating teachers, are introduced. Finally, the equivalence between the Learning Study group of teachers and the three teachers in the comparison group is established.

3.5.1. The Target Population: Experienced Physical Science Teachers

The target population of this study were experienced Physical Science teachers teaching in secondary schools in Gauteng and the students they teach at either Grade 10 or Grade 11 level. The specific criteria for this population included having at least five years teaching experience of the topic of stoichiometry. They also had to be currently teaching Physical Science at this level, since the literature indicates that the PCK develops with experience (Loughran *et al.*, 2012). Experienced teachers notice different aspects of classrooms when compared to novice teachers who often rely on surface features to analyse and understand problems (Livingston & Borko, 1989; Wolff, van den Bogert, Jarodzka, & Boshuizen, 2015). Expert teachers, therefore, can detect and recognise relevant information more rapidly than novice teachers (Wolff *et al.*, 2015). This is important in terms of studying the enactment of TSPCK evident in planning and observable in the classroom in response to unexpected comments or answers to scientific phenomena from students, since experienced teachers often have a greater representational repertoire or can spontaneously generate analogies to deal with students preconceptions (Chan & Yung, 2015; Clement, 1998; Clermont, Borko, & Krajcik, 1994). Experienced teachers are also more selective in the information they use during planning and interactive teaching (Livingston & Borko, 1989), which influenced the selection of the target population. The sampling of the target population is described in the next subsection.

3.5.2. Sampling for the Study

Due to limitations of time and access, the teachers who were approached to participate in Phase I of this study were teaching in secondary schools in Gauteng. The sampling of teachers for this phase of the study did not include any random sampling of the target population, and non-probability sampling, typical of research in education, was employed (McMillan & Schumacher, 2010). The sampling approach that was used was therefore purposive sampling (Cohen, Manion, & Morrison, 2007). Thirty-one respondents drawn from my personal network of teachers met at training workshops, cluster meetings, Grade 12 marking, peers completing post-graduate studies in science education and schools where I have previously taught were approached. This initial sample included teachers of both genders, from different population groups, teaching in both government and private schools, and also well-resourced and poorly resourced schools. Due to the geographical distribution of some of the teachers in Gauteng, they were given the option to return the instruments via the postal service (Bell, 2005). Thirty-one teachers returned completed TSPCK instruments and CK instruments.

For Phase II of the study, three teachers in the Master's program were approached to form a Professional Learning Community to participate in the Learning Study. These teachers were registered with the Division of Science Education within the School of Education at the University of the Witwatersrand for a Masters degree in Science Education by course work and a research project. This postgraduate degree the teachers were enrolled in can be completed either fulltime over one year or part-time over two years, with part-time students completing the research project during the second year of the programme. The Marang Centre for Mathematics and Science Education coordinates the research component of this postgraduate degree. One of the research thrusts of the Marang Centre is that of teacher education and professional development, with research aims that include research into the topic-specific PCK construct, the effects of interventions on the development of PCK in pre-service and practising teachers and the study of teachers' own PCK through self-studies. It was from the pool of part-time students in the programme, who had elected to complete research projects within this research thrust, after consultation with their respective supervisors, that a Professional Learning Community was constituted to conduct a Learning Study related to the teaching of stoichiometry. The next subsection introduces the team that constituted the PLC. Each of the participant's research projects investigated a particular

aspect of the Learning Study, either on their own PCK or PCK development or on the effect of the Learning Study as an intervention on practicing teachers' PCK development.

The teachers' participation in the Learning Study also formed the basis for this study. These three participants were sampled by case type (McMillan & Schumacher, 2010; Rollnick & Mavhunga, 2015). Typical case sampling was used in that the three participating teachers also all had at least five years teaching experience, had taught stoichiometry for five years, coincidentally teach at typical township schools and have good stoichiometric content knowledge. The Grade 11 student participants were from the selected teachers' classes. The three participating teachers in the comparison group were also sampled by case. These teachers taught at the same suburban school and were all teaching Grade 10 stoichiometry. The equivalence of the Learning Study group and the comparison group are discussed in Subsection 3.5.4.

3.5.3. Introducing the Team Members in the PLC

When establishing a Professional Learning Community, team members converge and unite on a common interest motivated by their personal expectations to determine if there is enough common ground to collaborate (Dooner, Mandzuk, & Clifton, 2008). For the teacher participants, their personal expectations related to completing their Masters Research project. For the supervisors, it related to not only supporting their students, but their participation as experts in chemistry education and PCK development. My personal expectation in terms of conducting this research and my role as facilitator and researcher-participant meant that, as a group, there was an identifiable shared domain of interest (Dooner *et al.*, 2008; Wenger, 2011). In this subsection, a brief biography of the team members involved in the joint enterprise centred on the development of their practice (Dooner *et al.*, 2008; M. K. Smith, 2003) is provided. Pseudonyms have been used to maintain anonymity for the participants.

Sipho, a teacher from Zimbabwe, teaches at a township school in the west of Johannesburg and has been teaching senior Physical Science since 2008. He completed his BSc honours degree in science education at the University of the Witwatersrand before commencing with the MSc programme. He first completed a Diploma in Education in science before obtaining a B.Ed degree majoring in chemistry in Zimbabwe. Sipho's supervisor, Maggie, initially obtained a B.Sc in education, teaching for a few years before moving into teacher education. She obtained her B.Sc Honours, M.Sc and PhD at the University of the Witwatersrand. She

has had experience in the development of research-based teaching and learning materials and teacher development programmes.

Tendani teaches at a township school in the east of Johannesburg and he is also from Zimbabwe. He has been teaching senior Physical Science since 2009. He initially obtained a B.Ed in Cuba in Physics and Mathematics and obtained a B.Sc Honours in Zimbabwe. Ellen, Tendani's supervisor, has extensive experience in chemistry education and science teacher education, which began in Swaziland before moving to the University of the Witwatersrand in 1990. She obtained her B.Sc at the University of the Witwatersrand and her M.Sc in England, returning to complete her PhD at the University of the Witwatersrand. As an expert, Ellen has published papers on the teaching and learning of science, relating to second-language teaching of science, students' alternative conceptions and conceptual change strategies, improving teaching of difficult chemistry topics and the development of teachers' PCK.

Sizwe, also originally from Zimbabwe has been teaching senior Physical Science for eight years. He is currently teaching at a township school in the west of Johannesburg. He obtained a Diploma in Education before completing his B.Ed in Science in Zimbabwe. He completed a B.Ed honours degree in science education through UNISA before registering for the M.Sc programme at the University of the Witwatersrand. Sandra, Sizwe's supervisor completed her B.Sc in chemistry at the University of the Witwatersrand and worked in the chemical industry before moving into teacher education. She also completed her M.Sc and PhD at the University of the Witwatersrand.

This subsection has provided a brief biography of the team '*drawn from a network of different schools and science education experts*', of the purposefully created community of practice organised around the joint activity of researching teacher knowledge and teaching practice, our team's shared interest (Dooner *et al.*, 2008; Hoadley, 2012; M. K. Smith, 2003). Purposefully created communities of practice, referred to as strategic communities, since the focus is on knowledge creation, have a high degree of connectivity and high institutionalisation (Hoadley, 2012). Connectivity, according to Hoadley (2012), refers to the social connectedness of team members, identity and the degree of interaction whereas institutionalisation refers to the composition, shared purpose and formalisation of the community. The social connectedness of the community was discussed when describing the relationships between team members, and the composition of the community has been

described in this subsection. A more detailed account of the activities of the Professional Learning Community is provided in Chapter 5. The next subsection outlines the equivalency of the teachers involved in the Learning Study with the comparison group of teachers.

3.5.4. The Learning Study Group and Comparison Group of Teachers

In the above subsection, the team that constituted the PLC were introduced. Included in this introduction were the three teachers in the Learning Study. In order to compare the impact on enacted TSPCK of participating in a Learning Study, which can be considered as an intervention, a comparison group was required and the Learning Study group needed to be similar to the intervention group (White & Sabarwal, 2014). The comparison group was deemed necessary in order to establish the impact of working collaboratively in a Learning Study on teachers' enacted TSPCK. This subsection is aimed therefore at arguing the equivalence of the Learning Study group of teachers and the comparison group. Table 3.1 below summarises these similarities.

Table 3.1: Table of baseline characteristics of the teachers in the intervention group and the comparison group

Characteristic / Teachers*	Learning Study Group			Comparison Group		
	Sipho (L01)	**Tendani (L02)**	**Sizwe (L03)**	**Janet (C01)**	**Christine (C02)**	**Hendrick (C03)**
Highest qualification	Registered for M.Sc in science education	Registered for M.Sc in science education	Registered for M.Sc in science education	HDE (Physical Science)	FDE in Biology	B.Sc Hons in Agriculture
Years of experience teaching Grade 11 Physical Science**	7	5	8	17	7	12
Score for TSPCK Instrument***	3.59	- 5.99	- 8.33	- 5.99	- 5.99	- 8.33
Score for CK Instrument (%)	87	80	67	93	80	73
School****	Mangosuthu Secondary	Juskei River Secondary	Rolihlahla Secondary	Eastmoor High	Eastmoor High	Eastmoor High
Grade taught (mole concept) for observation	Grade 11	Grade 11	Grade 11	Grade 10	Grade 10	Grade 10
Length of observation (minutes)	200	180	150	160	200	160
Resources in classroom	Chalk board	Chalk board	Smart board	Smart board	Smart board	Smart board

* Pseudonyms have been used for the teachers to ensure anonymity and the code used in the Rasch analysis is provided (see Chapter 4).
** Until the revision of the South African curriculum stoichiometry was only taught in Grade 11. With CAPS implemented in 2012 the topic is now introduced in Grade 10 and repeated in Grade 11.
*** Scores are based on the Rasch analysis of the TSPCK instrument. Refer to Chapter 4.
**** Not the real names of the schools. These have been invented by the researcher to ensure the anonymity of the teachers.

Firstly, the two groups represent convenience groups. The PLC, as described in subsection 3.5.3 was formed from teachers in a postgraduate Master of Science programme at the University of the Witwatersrand where I as the researcher was undertaking this study. These

teachers were completing a research project as part of the programme (see subsection 3.5.3). The teachers from the comparison group were all teaching at the same school, a large suburban school with at least three classes per grade doing Physical Sciences. Hendrick, as subject head for Physical Sciences informed me that as a group of teachers they 'do their own thing[7]' and only share assessment tasks. As a group of teachers, they also only meet once a term. At the beginning of the school year, this meeting is to decide who will set class and standardised tests. Therefore, the meetings are related more to the logistical aspects of teaching the subject. The teachers do not plan together and are left to their own devices in the classroom and try to cover the work outlined in the work schedule provided by the Department of Basic Education in the same timeframe for testing purposes. Christine and Janet both commented that even sticking to their assessment plan is difficult as Hendrick is often a week behind the schedule and they both mentioned that, during the period of observation, it was the first time Hendrick kept pace with content coverage[8].

Secondly, the teachers in each group were experienced Grade 11 Physical Science teachers with five or more years experience teaching Grade 11. The teachers who completed the TSPCK Instrument were purposively sampled for this reason (see subsection 3.5.2). As is evident in Table 3.1, Tendani (L 02) had the least experience in teaching Grade 11 stoichiometry, with only five years teaching the grade and Janet (C01) had the most experience having taught Grade 11 for seventeen years. The number of years experience teaching Grade 11 is therefore an indication of their experience in teaching the topic of stoichiometry, as this topic has been part of the Grade 11 syllabus since the 1980s.

Thirdly, the teachers' level of TSPCK and CK as measured by the developed instruments (see Chapter 4) were similar. All the teachers' scores on the TSPCK instrument as determined by the Rasch analysis (see Chapter 4), with the exception of Sipho (L01) were below the mean of the thirty one teacher sampled. Sipho's average score was above the mean average since he scored better in the components of curricular saliency, what is difficult to teach and representations (see Tables 5.2 and 5.3). Sizwe (L03) and Hendrick scored '1' for the component of curricular saliency and conceptual teaching strategies respectively. However, other than these differences, the scores for each component of TSPCK, as measured by the

[7] Extracted from field journal based on a conversation when meeting to discuss lesson observations.
[8] Extracted from field journal from conversations with the teachers during the observation period.

instrument, were the same. In terms of content knowledge, all the teachers were determined to have adequate content knowledge, scoring above 60%. All the teachers except Sizwe scored more than 70% (see Table 3.1).

Table 3.1 also includes information about the school, the grade the lessons were taught to, the length of the lessons observed in hours and the availability of resources in the classroom. Although the comparison group taught Grade 10 whereas the Learning Study group taught Grade 11, the content coverage was the same. As mentioned in Chapter 4, when designing the TSPCK Instrument, a document analysis was undertaken of the CAPS curriculum. The core concepts in both Grade 10 and Grade 11 are the same in both grades, with the only differentiation related to the types of stoichiometric problems (see Appendix 5 for results of the document analysis). For both groups of teachers, the purpose of the lessons related to teaching students about the mole concept and both groups were taught the big idea related to the mole concept (see Chapter 4). The resources used in the Learning Study were made available by the university to the Learning Study group but the teachers in Eastmoor High[9] used their own school resources and were unaware of any of the planning or activities of the Learning Study group. The length of time the teachers were observed teaching the mole concept, ranged from 150 minutes to 200 minutes (see Table 3.1).

This section had described the target population for this study and how purposive sampling was used for Phase I of the study. From this pool of teachers, two convenience samples were drawn for the collective case studies. The first, the Learning Study group of teachers, were all completing a post-graduate M.Sc degree. These teachers and their supervisors, as experts in Chemistry education, formed a PLC in Phase II of this study. The team was introduced in subsection 3.5.3. Finally, this section compared the teachers in the Learning Study group and the teachers from the comparison group in subsection 3.5.4. In the next section, a brief outline of the Learning Study, as the treatment, is described. A detailed account of forming the PLC and the activities of the Learning Study is provided in Chapter 5.

[9] For purposes of confidentiality this is not the actual name of the school the comparison group taught at. The name is an invention of the researcher to ensure the anonymity of the teachers.

3.6. Treatment

In the literature review, the potential of a Learning Study as a means of professional development was described. Below, an outline of the program for the study is provided. As mentioned above, the teachers participating in the Learning study were drawn from teachers who are currently enrolled in the Master of Science programme in science education. The focus of the Learning Study was to develop TSPCK for the topic of stoichiometry through the collaborative planning of a lesson for the mole concept, one of the big ideas for stoichiometry. During Phase I of the study, problematic areas in the teaching of stoichiometry were identified and these helped frame aspects of the Learning Study.

The first session of the Learning Study took the form of a workshop which focused on aspects of the big ideas for teaching stoichiometry. In this workshop, the Learning Study group of teachers were introduced to the components of transformation that constitute the TSPCK model, including learner misconceptions in stoichiometry, aspects that are difficult for students to understand and the three levels of representation (Mavhunga, 2012).

As part of the first workshop, descriptions of activities with a focus on conceptual teaching strategies used by the researcher when teaching stoichiometry were described. To engage the participants with the TSPCK model, they were asked to identify the components of TSPCK in the strategy. In the second session, the lesson was planned using a CoRe that has been adapted to follow the format of the TSPCK model (Mavhunga, 2016) from which a common lesson plan was produced. A CoRe, or Content Representations, provides an overview of the content taught when teaching a particular topic (Mulhall, Berry, & Loughran, 2003). CoRes are considered a useful method for eliciting PCK that is centred in a teacher's knowledge and pedagogical skills (Kind, 2009b). Capturing and portraying of PCK through CoRes is described as a way of seeking to provide examples of best practice (Gess-Newsome, 2015). These sessions were video-taped to develop rich descriptions of the process. The lesson was then taught by me and videotaped. At the start of the lesson, the students completed a short diagnostic pre-test, and a post-test was done after the lesson.

The recorded lesson was viewed by the participating teachers to evaluate the effectiveness of the lesson, before meeting to discuss the lesson. Improvements were made to the lesson plan, based on the analysis of the pre-lesson and post-lesson diagnostic tests completed by the students, and the discussion of the lesson before the participants taught the improved lesson

with their class. This lesson was also videotaped in order for the participants to provide constructive feedback to their peers and reflect on their own teaching practice. These video lessons were analysed to describe the impact of collaborative planning on the teachers' TPCK development and the enactment of TSPCK in the classroom. A detailed account of the activities of the PLC and the Learning Study is provided in Chapter 5.

3.7. Data Collection and Data Analysis

In this section, an overview of data collection and analysis of data is provided. This is outlined for each sub-research question and follows the chapter outline, which was described in Chapter 1. The collection of data for this study was guided by the core features outlined by Desimone (2009) for professional development, including that participants' knowledge be developed and that this knowledge be used to improve their content and/or classroom enactment. However, in order to investigate teacher knowledge development and impact on classroom enactment, a measure of this knowledge before the professional development intervention was required, which necessitated the design and validation of instruments. A multiphase mixed methods design was therefore employed to answer the incremental research sub-questions (Creswell, 2012; Rollnick & Mavhunga, 2015) related to the quality, development and impact on classroom enactment of this knowledge. The data collection methods for each phase are outlined below along with how the data was analysed. Furthermore, a clear indication of whether the data collection is qualitative or quantitative is provided for each phase of the study (Creswell, 2012).

3.7.1. Measuring the Baseline Quality of Teachers' TSPCK

An exploratory-sequential mixed methods design is typical for instrument design (Creswell, 2012) and was essential for this study since no existing instruments existed to measure TSPCK in stoichiometry. Figure 3.1 provides an overview of the data collected during Phase I of this study. The design and validation of the instrument are reported on in my M.Sc Research report (Malcolm, 2015). This subsection focuses on the teachers' responses to the instruments to determine the baseline quality of experienced teachers' TSPCK in stoichiometry.

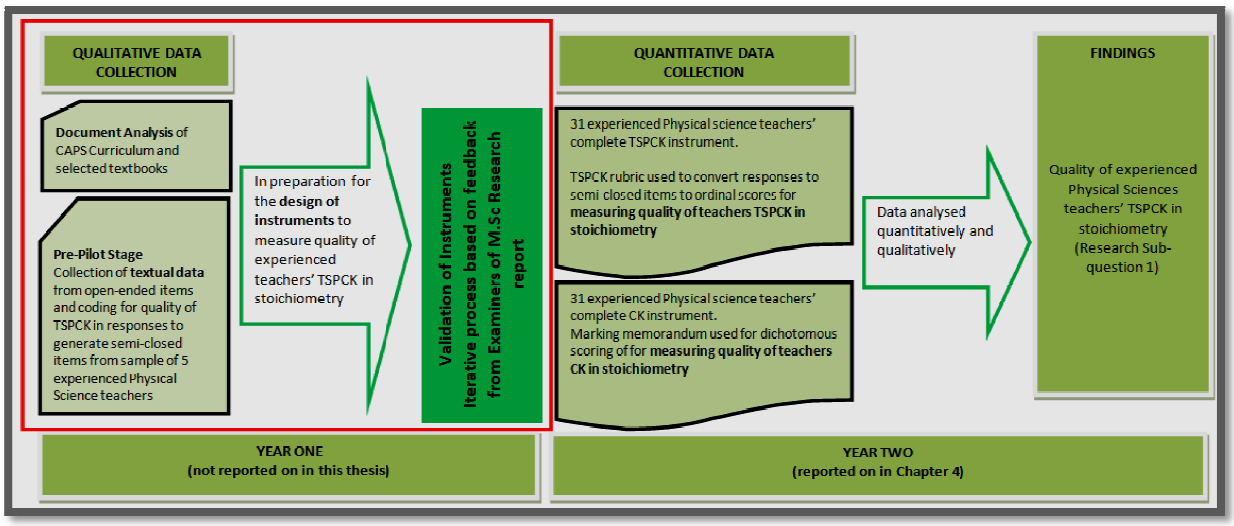


Figure 3.2: Summary of Phase I exploratory sequential design data collection for the study

Thirty-one experienced Physical Science teachers teaching at schools in Gauteng completed the TSPCK instrument, which is described in the next part of this subsection. The teachers who participated in the Learning Study and the comparison group in Phase II were drawn from this group of teachers. The TSPCK rubric, described in detail in Chapter 4 was used to convert the responses to ordinal scores for the quantitative analysis to determine the quality of the participants' TSPCK. When the TSPCK instrument was administered, the participants also completed the content knowledge instrument that was scored using a marking memorandum (see Figure 3.2). This data was analysed both qualitatively and quantitatively to determine the quality of experienced Physical Science teachers' TSPCK in stoichiometry.

Paper-and-Pencil Instruments to Collect Data for Baseline Assessment of the Quality of TSPCK

The paper-and-pencil instruments used for data collection were questionnaires and diagnostic tests. As a research tool, questionnaires are widely used as a procedure for collecting information for numerous reasons. These include being relatively economical to administer, ensure the standardisation of questions and can be written for specific purposes (McMillan & Schumacher, 2010; Opie, 2004). The TSPCK instrument and CK instrument, designed, developed and validated during the first phase of this study (Malcolm, 2015) provided the quantitative data related to the quality of teachers' TSPCK and content knowledge. The final version of both the TSPCK Instrument and the CK instrument are in Appendix 2. The data from these instruments helped inform the professional development intervention but the TSPCK instrument also served as the pre-test and post-test to measure change in teacher

knowledge. Since the aim of the cyclical process of a Learning Study is to improve practice related to planning a lesson to teach one gate-keeping concept in stoichiometry, a pre- and post-diagnostic test were administered to learners to determine aspects of the lesson that needed to be revised. The questions were selected from the same CK instrument administered to the teachers. The student diagnostic test is also included in Appendix 2.

(i) The TSPCK Instrument

The TSPCK instrument items followed the format utilised by Mavhunga (2012), who proposed the model for TSPCK and designed an instrument for measuring teachers' PCK in chemical equilibrium. In this study, an instrument was designed to measure TSPCK in stoichiometry. The items were constructed according to the five knowledge components of the TSPCK model described in the literature review (Mavhunga, 2012), as shown in Table 3.2 below.

Table 3.2: Types of questions to be designed for the various components of TSPCK in stoichiometry

Component of transformation	Type of Questions
Learners' prior knowledge (LPK)	Various teaching scenarios in which teachers respond to learners' statements that highlight alternative conceptions or problems in stoichiometry.
Curricular saliency (CSA)	Questions relating to identifying the big ideas in stoichiometry and various aspects related to this component, such as the sequencing of these ideas when teaching and construction of a concept map.
What makes the topic easy or difficult to understand (WDT)	A question that asks teachers to identify why learners find stoichiometry difficult to understand and why it is difficult to teach.
Representations (REP)	Different representations used in stoichiometry are provided reflecting concepts at macroscopic, symbolic and microscopic levels and teachers are asked to respond on these representations.
Conceptual teaching strategies (CTS)	Teachers are provided with teaching scenarios of aspects of stoichiometry that are difficult or have alternative conceptions to teach and asked to respond by providing a suitable teaching strategy.

The validity and the reliability of the TSPCK instrument is outlined in the report on the design and validation of the instrument (Malcolm, 2015). The reliability indices are included below in Table 3.3 to highlight that a valid and reliable instrument was used to determine the baseline quality of the teachers' TSPCK in stoichiometry.

Table 3.3: Table of summary statistics for person and item reliability of TSPCK instrument (N = 31)

Person separation reliability	Person reliability Index	Cronbach's KR-20 alpha	Item separation reliability	Item reliability index
2.88	0.89	0.82	10.52	0.99

(ii) The Content Knowledge Instrument

A Content Knowledge, or CK instrument, a conceptual diagnostic instrument and algorithmic test on stoichiometry compiled from various sources, consisting of short, closed-ended diagnostic questions was used to measure the content knowledge of teachers. Content knowledge is a prerequisite for the development of PCK (Gess-Newsome, 1999b; Ozden, 2008), hence the need to measure respondents' CK. Three aspects of stoichiometry were covered in the CK instrument, namely, the mole concept, concentration and limiting reagents. Sections of the CK Achievement instrument were used as the pre- and post-diagnostic tests administered to learners in Phase II, to gauge aspects of the planned lesson that needed to be revised. The final version of the CK instrument is included in Appendix 2.

The validity and the reliability of the CK instrument is also outlined in the report on the design and validation of the instrument (Malcolm, 2015). The reliability indices are included below in Table 3.4 to highlight that a valid and reliable instrument was used to determine the baseline quality of the teachers' CK in stoichiometry.

Table 3.4: Table of summary statistics for person and item reliability for the CK instrument (N=31)

Rasch analysis	Person separation reliability	Person reliability Index	Cronbach's KR-20 alpha	Item separation reliability	Item reliability index
15-item instrument	1.43	0.67	0.79	2.13	0.82

Qualitative and Quantitative Analysis to Describe Quality of Respondents' TSPCK and CK in Stoichiometry

For Phase I of this study a quantitative analysis of the TSPCK and CK instruments using the Rasch statistical model was conducted to determine Rasch measures for the teachers' TSPCK and CK. Once the validity and reliability of the instruments were established (Malcolm, 2015), an in-depth analysis of the responses was conducted to determine problematic areas in the teaching of stoichiometry and to inform aspects of the Learning Study. From the in-depth analysis, patterns of responses were confirmed through cluster analysis to determine the quality of teachers' TSPCK that helps establish the goal for improving TSPCK and classroom enactment in the Learning Study, of Phase II of this study. Therefore the data from the validated TSPCK and CK instruments for the thirty-one teachers who completed the instruments were analysed both quantitatively and qualitatively to determine the quality of teachers' TSPCK. Each stage of data analysis in Phase I is described below.

(i) Quantitative Analysis of the TSPCK Instruments

The TSPCK instrument that was designed was administered to a sample of thirty-one experienced teachers. Their responses were scored for each category using a TSPCK rubric (Park & Oliver, 2008). In scoring the responses, the qualitative description provided by the teachers was used in determining the qualitative category on the rubric, and therefore the numerical score on the rubric. So the rubric was used to convert participants' responses to ordinal scores. To ensure validity of the scores, the instruments were scored independently by two other raters to determine inter-rater reliability. This is described in Chapter 4. The ordinal scores from the rubric provided the data needed in determining the baseline quality of teachers' TSPCK in stoichiometry. The measure of teachers' TSPCK in stoichiometry was determined, using the Rasch statistical model, which according to Bond and Fox (2001), converts raw data scores to probability measurements on an equal interval scale. The Rasch model transforms raw scores, in this case ordinal scores, into linear measures, located on a scale with equal intervals (Bond & Fox, 2001). Mavhunga (2012) described how this allows an empirical determination to be made, with respect to a person's ability to respond to a hierarchy of item difficulty. According to Bond and Fox (2001), the measured performances reflect an underlying construct. The Rasch analysis was done using *Winsteps Ministeps*. This analysis is described in more detail in Chapter 4.

(ii) Quantitative and Qualitative Analysis of the CK Instruments

The CK instrument was scored dichotomously and on a continuous scale using a marking memorandum to obtain a total score of 15. During the scoring process, a scoring sheet (see Appendix 11) was used to capture scores for each question. The scoring process is described in more detail in Chapter 4. The scoring sheet was used so that the individual scores could be captured and subjected to Rasch analysis using *Winsteps Ministeps*. The dichotomous scores were used to determine the baseline quality of respondents' stoichiometric content knowledge.

In addition, responses to an item in which respondents were asked to define the mole were coded. Coding, the process of labelling text, was done in order to label the participants' conceptualisation of the mole (Creswell, 2012). The various conceptions of the mole are described in chapter 2. The participants' conception of the mole was also captured on the score sheet (see Appendix 11) and coded as F1, F2, F3 and F4. The definitions of the mole

that were inconsistent with the SI definition were labelled as F1 to F3 and the scientifically correct definition as F4, as described by (Strömdahl *et al.*, 1994). Evidence of respondents' conception of the mole was also identified in the TSPCK instrument. It was considered important to gauge the respondents' conception of the mole since this has an impact on the teaching approach when teaching stoichiometry (Tullberg *et al.*, 1994).

(iii) Qualitative Analysis of Responses to TSPCK Items in Instrument

The individual responses to the TSPCK items, according to Bell (2005, p. 203), represent 'a hundred different pieces of information that will mean nothing to a researcher unless they have been categorised and interpreted'. The scoring of the responses using the TSPCK rubric converted qualitative responses to the items in a quantifiable form, but there was also a need to identify specific problematic areas for professional development that required some form of generating ideas (Glaser, 1965). Therefore, the individual responses were captured on an *Excel* spread sheet. in order to look for similarities and differences in the responses, identify patterns in the responses and look for groupings in terms of the quality of TSPCK (Bell, 2005). Figure 3.5 on the next page shows the responses from three participants that were identified through the Rasch analysis as exhibiting basic, developing and exemplary TSPCK.

As is evident in Figure 3.3 the respondents' CK score, conception of the mole and ordinal score for each category were recorded. The responses to each of the five items were captured; however, only the responses to the last two items are shown in Figure 3.3, the responses were coded using a colour code as shown in Figure 3.3. The data was analysed using the constant comparison method to generate a 'plausible suggestion about a phenomenon' (Glaser, 1965, p. 438), namely the quality of teachers' TSPCK and approach to teaching stoichiometry. The responses to the different items were constantly compared. For example, the responses to learner prior knowledge items were compared with the conceptual teach strategy item and if the teachers' identified the learner errors explicitly, the selection of the representation in the item on representations was compared with the representations mentioned in the conceptual teaching strategy item. The logit scores form the Rasch analysis was compared with the level of integration of the five components in responding to the five items. The teaching strategies were compared with the respondents' conception of the mole (Tullberg *et al.*, 1994). The constant comparison was therefore used as a tool for discovering patterns in the responses to develop a picture of the quality of teachers' TSPCK (Boeije, 2002).

Respondent	CK Score	Conception of Mole	Category D: Representations		Category E: Conceptual Teaching Strategy			
			Rubric	Response	Rubric	Learner error	Strategy	Representations used
V05 Jeannine	100%	F3 (number)	4	Use REP 3 as the lesson outcome (build as teaching) Use the macroscopic ideas of molar volume and mass of gases before introducing Avogadro's number and linking it to amu and the sub-microscopic representation of molecules and then balance chemical equation (symbolic representation).	3	Broadly identifies the learner errors as related to not having an understanding of limiting reagent	Firstly, explain what is meant by limiting reagent using example from previous lesson Then using the balanced chemical equation, and given information calculate the number of moles and compare the quantities using the balanced equation.	Macroscopic analogy for limiting reagent Symbolic - use of formula to find amount Symbolic - compare with molar ratios in balanced chemical equation
L01 Sipho	87%	F4 (SI Unit)	3	Use REP 3 to teach balancing chemical equations molar ratios and conservation of mass/atoms (Not linked to actual stoichiometric ideas and does not refer to macroscopic aspect)	2	Explicitly identifies both errors. Learners read equation and think reactant in smaller amount (in terms of molar ratios) is limiting reagent and that the reactant with least amount in terms of mass is the limiting reagent	Get students to convert kilograms to grams The tell them to use formula to find the number of moles of reactants Then compare with chemical equation to find limiting reagent	Symbolic – use of formula to find amount Symbolic – compare molar ratios with balanced chemical equation
C02 Christine	80%	F3 (number)	2	Use REP 2 (formula triangle) Use it to calculate molar masses, mass and amount in solving stoichiometric problems.	2	States students didn't do calculations and that it is easy to make a mistake (So inferring must calculate the amount from the given mass)	Remind students of molar mass and calculating it from the periodic table Remind students of molar ratios and the formula n = m/M.	Symbolic – the periodic table Symbolic – the balanced chemical equation Symbolic – formula to calculate amount

Figure 3.3: Extract for Excel Spread Sheet Capturing Responses to TSPCK[10] Items

(iv) Correlation Analysis of TSPCK and CK Scores

The investigation of the quality of teachers' TSPCK was extended to determining the relationship between respondents' TSPCK and CK. This was done using correlation statistics that are used to measure the degree of association between two sets of scores (Creswell, 2012). The correlation between TSPCK in stoichiometry and stoichiometric CK was determined using *Pearson's product-moment correlation* of the Rasch measures. The meaningfulness of the correlation analysis was established using non-parametric significance testing techniques because of the small sample size of thirty-one teachers (Conover, 1980). Since two different treatments were conducted, namely the TSPCK instrument and the CK instrument on the same sample, the test that was suitable for use in the analysis of the data was the *Wilcoxon Paired Signed Rank test* (Stangroom, 2017). The results of this analysis and the constant comparison analysis are discussed in Chapter 5.

(v) Cluster Analysis to Determine Teaching Profiles for Teaching Stoichiometry

Based on the constant comparison analysis and the correlation analysis, categories of teaching profiles were developed inductively (Boeije, 2002). Based on the literature reviewed

[10] REP is the abbreviation used for representations. See the TSPCK Instrument in Appendix 2.

in Chapter 2, it was evident that many teachers, based on their responses to the items in the TSPCK instrument and not classroom observations, therefore self-reported that they teach stoichiometry algorithmically (Stamovlasis *et al.*, 2005). Tullberg *et al.* (1994) also reported that the teaching strategies used by teachers in teaching stoichiometry are linked to their conception of the mole. However, Bell (2005) cautions against placing too much reliance on preconceived ideas. On the other hand, the data indicated clustered data and the intrinsic structure of the groupings was determined by cluster analysis (Fraley & Raftery, 1998). Cluster analysis is a convenient method for identifying homogenous groups or clusters in data (Sarstedt & Mooi, 2014). It develops empirical groupings based on similarities in the variables of interest (Punj & Stewart, 1983; Tryfos, 1998). A computer program designed to create market segments was used to run the cluster analysis (Fripp, 2016). The raw ordinal scores for the TSPCK items, the CK score and the teachers' conception of the mole, assigned numerical values based on the conception (i.e. 1 for an F1 conception, 2 for an F2 conception and so on). The analysis of the data from Phase I of the study was used to guide aspects of the professional development activity in Phase II. In the next subsection, the analysis of the data for the convergent parallel design of Phase II is described.

3.7.2. Phase II: Convergent Parallel Design for Determining Impact on TSPCK Development and Classroom Enactment

Although professional development is viewed as any activity that is intended to improve performance, Desimone (2009) explains the importance of making decisions about what data to collect when conducting studies related to the impact of a professional development activity. Sustained Learning Studies can help teachers build a shared body of professional knowledge (Chokshi & Fernandez, 2004) since the process of developing a detailed lesson plan and discussing it with colleagues has proved a powerful tool for instructional improvement (R. Stewart & Brendefur, 2005). This type of professional development is an example of a situated view of learning, as it is interactive and involves participation as a social practice that can provide a broader framework for understanding and improving educational practice (Greeno, 1997). This, therefore, required a convergent parallel design and Figure 3.4 shows the points during the professional development activity where data was collected.

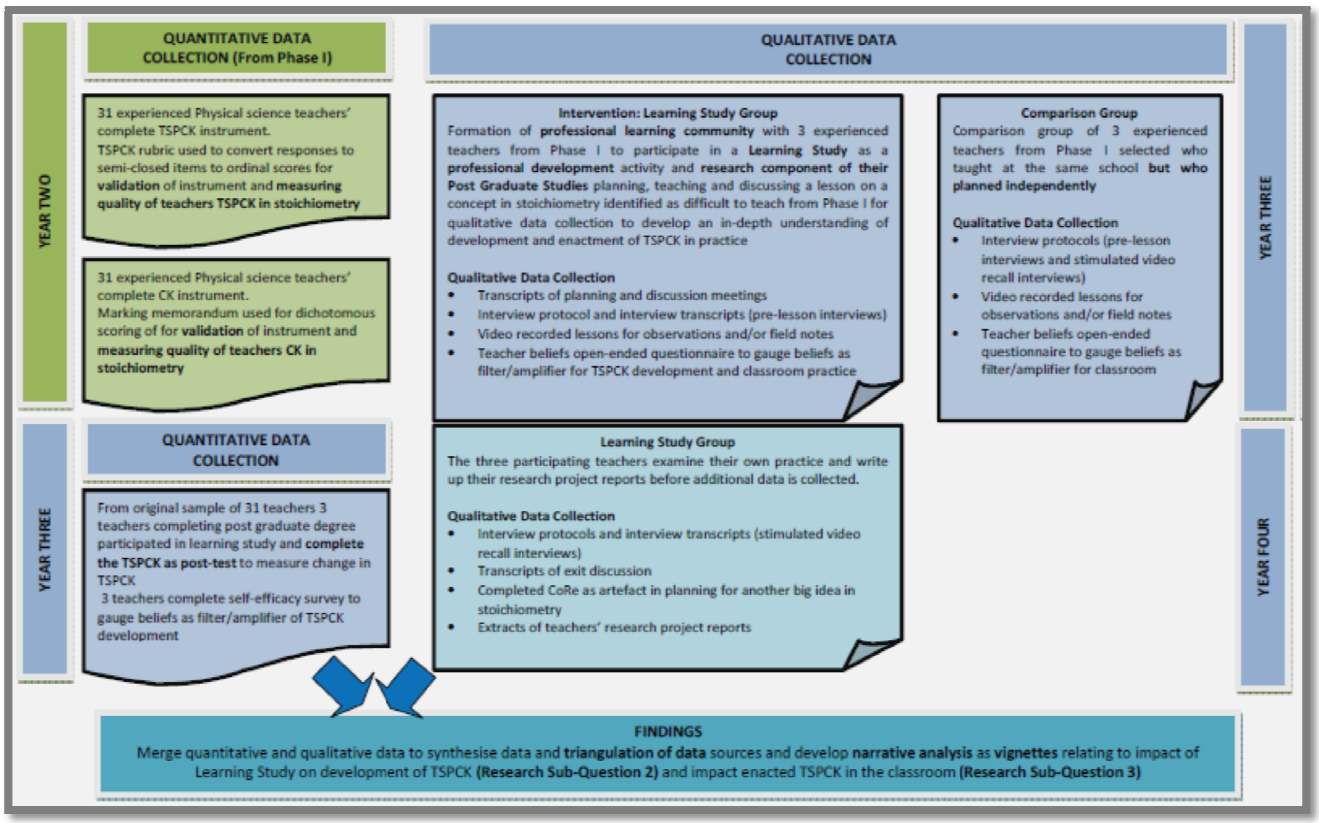


Figure 3.4: Summary of Phase II Convergent Parallel Design Data Collection for the Study

The data collection for this study involved paper-and-pencil instruments, observations and interviews (see Figure 3.4). As suggested by Desimone (2009), there is a need to focus on those characteristics of a Learning Study that make it effective for teacher learning and changing teacher practice. According to Lewis (2004), the key features are a focus on a particular topic, especially where a new approach is advocated, the lesson observation and post-lesson discussions of observed lessons and developing an 'eye for the student' and looking for evidence of student learning. Desimone (2009) outlines the various strengths and the weaknesses of the different data collection methods used to measure teacher professional development such as surveys, observations and interviews and argues that each has its merits if best practice is followed. Data was collected at various stages of this phase of the study, using paper-and-pencil tests designed specifically for this study in Phase I, a questionnaire and survey, observations, artefacts, interviews and field notes of the observation of the lessons (see Figure 3.4). The planning meetings, post-lesson discussion meetings and exit discussion were videotaped and a video-stimulated recall interview (SRI) was conducted with each participant after they had completed their own analysis task (Sato, Akita, & Iwakawa, 1993). The various data collection methods, both quantitative and qualitative described

below, were triangulated to provide a more comprehensive set of data (McMillan & Schumacher, 2010).

Paper-and-Pencil Instruments to Collect Data for TSPCK Development

The paper-and-pencil instruments used for data collection were questionnaires and diagnostic tests. The TSPCK instrument served as the post-test to measure change in teacher knowledge of the teachers participating in the Learning Study. An open-ended beliefs interview instrument developed by Luft and Roehrig (2007) as an interview protocol and adapted for written responses by Mavhunga (2012) and a self-efficacy survey (Tschannen-Moran, Hoy, & Hoy, 1998), with scaled items to capture participants' opinions of their teaching effectiveness was also to be administered (McMillan & Schumacher, 2010). The beliefs and self-efficacy questionnaire is included in Appendix 2. The teacher beliefs questionnaire provided qualitative data, and the self-efficacy survey provided quantitative data to provide insight into how beliefs act as filters of teacher knowledge (Gess-Newsome, 2015). In order to minimise bias from these paper-and-pencil instruments and questionnaires, multiple data was collected employing various methods such as field notes and interviews and were triangulated (Desimone, 2009). These paper-and-pencil instruments and questionnaires were administered by me as the researcher. Copies of all the questionnaires administered are included in Appendix 2.

Adaptation of Instruments to Capture Filters & Amplifiers Influencing TSPCK

There are various filters and amplifiers that influence teachers in the implementation of specific teaching strategies and influence their classroom enactment, such as their beliefs and self-efficacy (Gess-Newsome, 2015). From the PCK summit and the proposed consensus definition of PCK, the basis for the development of the consensus model of teacher professional knowledge (Carlson *et al.*, 2015) that forms part of the theoretical framework for this research, these filters are acknowledged. Teacher beliefs are captured in the 'reasoning behind, and enactment of teaching particular topics in particular ways' and are part of a teacher's thinking process (Clark & Peterson, 1986). It is important to note that for this study these teacher attributes captured in the beliefs and self-efficacy questionnaires are not conceptualized as a part of teachers' TSPCK but rather factors influencing them. Capturing these aspects is therefore important due to their explanatory power when describing teachers' classroom enactment.

Two existing instruments described above were combined into a single instrument for administration purposes. The first was the teacher belief questionnaire, originally developed by Luft and Roehrig (2007) as an interview schedule. However, changes to the format were made by Mavhunga (2012) and it was converted into a questionnaire more context-relevant for South Africa. The use of the written questionnaire, rather than interviews, was based on several considerations. Firstly, the questionnaire was administered to the three teachers involved in the Learning Study. By the time we had convened the Professional Learning Community, we had already met on a number of occasions for logistical reasons and the Learning Study schedule meant that, as a participant observer, the participants would be familiar with my presence. Therefore, the teachers might answer the questions based on what they thought I might like to hear (Cronk & West, 2002). This was avoided by using the written format questionnaire and gave the teachers some degree of privacy (Mavhunga, 2012). Since the beliefs questionnaire served only to identify possible amplifiers and filters, eliciting the teachers' beliefs was not central to answering the research questions (Alshenqeeti, 2014), and the written format was decided on. This interview protocol was originally administered to beginning chemistry teachers (Luft, 2009), hence its relevance for this study. For self-efficacy, there are often issues around measurement for broader categories of teaching, so its measurement should be done in specific contexts, such as when teaching a particular topic (Nie, Lau, & Liau, 2010; Tschannen-Moran & Hoy, 2001; Tschannen-Moran *et al.*, 1998), The Ohio State teacher Efficacy scale, with twenty four scaled items, was used to compile the second part of the questionnaire, due to its reasonable validity and reliability compared to other instruments (Tschannen-Moran & Hoy, 2001). However, as recommended by Nie *et al.* (2010), items were adapted specifically for the context of teaching stoichiometry. The combined questionnaire is included in Appendix 2.

Observations to Collect Data on TSPCK Development and Impact on Practice

The participants of the learning study group were observed during the planning and discussion sessions of the Learning Study and when teaching the planned lesson. It was during these sessions that engagement with the components of TSPCK could be observed in planning and providing feedback to peers in a social setting as it occurs naturally (McMillan & Schumacher, 2010). The observations allowed for the collection of open-ended information regarding their engagement with the components of TSPCK (Creswell, 2012). The observation was continuous observation since the participants' engagement with the

TSPCK model is described over the period of the Learning Study (McMillan & Schumacher, 2010). These sessions were video-recorded and transcribed for in-depth analysis and coding of the participants' engagement with the components of TSPCK. A sample of the transcriptions in included in Appendix 18, Since I, as the researcher, was part of the Learning Study and was therefore a participant observer (Creswell, 2012) during the planning phase and teaching the lesson first for the initial discussion, it is acknowledged that this can affect the behaviour of the participants (McMillan & Schumacher, 2010). The observations and transcriptions of the meetings were the main data collecting method of capturing the development of the participants' TSPCK. These were transcribed after all the cycles of the Learning Study were completed to help ensure the necessary detachment in moving from participant in the PLC to researcher.

The lessons taught by each teacher, the three in the Learning Study group and in the comparison group were also video recorded. Firstly, for the Learning Study group, the video-recorded lessons provided the visual anchor for them to reflect and inquire into their own classroom enactment (Harlin, 2014). In addition, video-recording the lessons allowed for a deeper in-depth analysis using the construct of TSPCK (Tröger, Strübe, Sumfleth, & Tepner, 2014). The use of video recordings to capture observations also allows for information to be recorded 'as it occurs in a setting to study actual behaviour' (Creswell, 2012, p. 213) which allows the researcher to explore phenomena in-depth (Cohen *et al.*, 2007).

Interviews to Collect Data on TSPCK Development and Impact on Enacted TSPCK

Interviews, which allow participants to voice their experiences in the Learning Study or teaching the lesson on stoichiometry of a gate-keeping concept (Creswell, 2012), were conducted both individually and as a group. According to Cohen *et al.* (2007), interviews are useful in that they allow participants to express their thoughts freely and a researcher to explore a phenomenon in-depth. Individual interviews were conducted before and after teaching the lesson individually and as a group in a group discussion. The interview schedule consisted of semi-structured questions, with the specific intent to determine what benefits or challenges the participants experienced from participating in the Learning Study, or in teaching the lesson, and to follow up responses to the paper-and-pencil instruments (McMillan & Schumacher, 2010). The interview protocols are included in Appendix 2. The interviews were recorded in either audio or video and transcribed for careful analysis.

Samples of the interviews are included in Appendix 20. The interviews were used to collect data on both the teachers' TSPCK development and the impact of the learning study on enacted TSPCK and the interview protocols are discussed below.

Interview Protocols

The interviews were conducted with the teachers of the Learning Study at different phases of this study. These interview protocols were first piloted with the teachers of the comparison group when their lessons were observed. The first interview with teachers from the Learning Study group occurred directly before each teacher taught the lesson. This was done to gain an insight into the teachers' perception of the students, the school and classroom context, an overview of the lesson, awareness of possible misconceptions and possible student difficulties in grasping concepts in the lesson. The second interview was conducted six months after teaching the lesson, and the participants had watched the recorded lesson and completed their own analysis thereof for their M.Sc research projects. This was done to allow them time to write up their research reports so as not place unnecessary demands on their time. It was also reasoned that by conducting the interviews after they had written their reports they would have a deeper understanding of their reasons for the enactment of the lesson. During this interview, questions were structured to gain an insight into how they felt the lesson went; any unplanned episodes that occurred and the strategies they used to help students learn. The second interview included a video-stimulated recall component that served as a secondary data source for identifying episodes of TSPCK enactment. This interview aimed at capturing teachers' reconstructed thought processes to episodes that deviated from the planned lesson, in which they used their knowledge to formulate responses to unexpected events or to describe their thinking for using particular strategies or examples when teaching. Therefore, interviews were considered appropriate here since they allowed for 'direct explanations of human actions through a comprehensive speech interaction' (Alshenqeeti, 2014, p. 40). The interview protocol was similar to that used in a study for on-site PCK development (Chan & Yung, 2015). The third interview, a semi-structured group discussion, was conducted after the Learning Study with two of the three participants to gauge conceptions about the impact of the Learning Study on aspects of their professional development. The interview protocols are included in Appendix 2.

Completed CoRe to Collect Data on TSPCK Development

During the planning of the lesson for the Learning Study, a CoRe was compiled for the selected big idea related to the mole as a bridge between the macroscopic and microscopic views of matter. Since CoRes are considered useful to capture manifestations of PCK (Gess-Newsome, 2015), two of the participants in the Learning Study group completed their own CoRe for at least one more big idea in stoichiometry. The CoRe used was specifically modelled on the components of TSPCK, and is referred to as an adapted CoRe (Mavhunga, 2016). A sample of an adapted CoRe completed by a teacher is included in Appendix 20.

Reflective Journal

A reflective journal was also kept during Phase II of the study. These typed notes about my thoughts, reactions and experiences during the Learning Study meetings and the lesson observations served to show the extent of my influence during the research process (Cohen *et al.*, 2007; Lodico, Spaulding, & Voegtle, 2010). As the facilitator of the PLC meetings and therefore a participant observer, this was useful in clarifying my own interests and positions during the different cycles of the Learning Study, thereby creating transparency in the research process (Ortlipp, 2008). Page samples are included in Appendix 20.

Triangulation of Data Sources

The data collection methods described above, along with the reflective journal, were integrated in the convergent parallel design in order to develop a comprehensive understanding (McMillan & Schumacher, 2010; Moran-Ellis, Alexander, Cronin, Dickinson, Fielding, Sleney, & Thomas, 2006) of the impact of a Learning Study on the participants' TSPCK development and classroom enactment. According to Moran-Ellis *et al*. (2006), the generation of a tangible relationship between methods is essential in a mixed methods approach. Figure 3.5 highlights how the various data collection methods were integrated and triangulated to develop a robust explanation of the impact of professional development on teachers' TSPCK in stoichiometry (McKim, 2015). The red boxes represent the two aspects of the research being investigated in Phase II of this study: the TSPCK development and impact on classroom enactment through participation in a Learning Study. Figure 3.5 also highlights how the data was converged in the convergent parallel design used in Phase II.

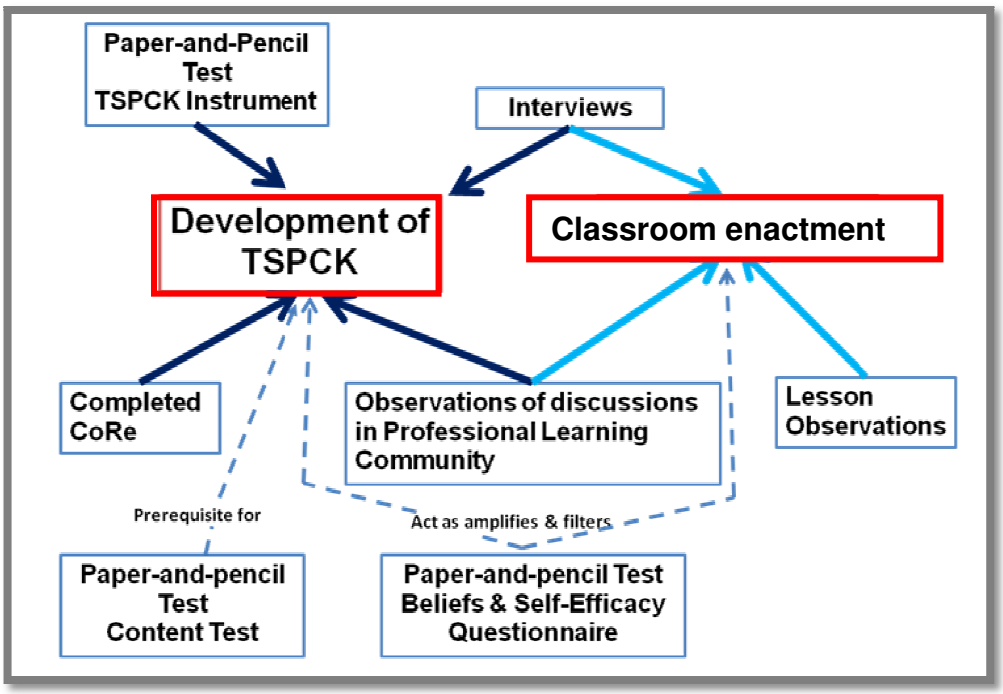


Figure 3.5: Integration and triangulation of data collection methods for convergent parallel design of Phase II

Phase II Data Analysis: Development of TSPCK

In a convergent parallel design, quantitative data and qualitative data are collected and analysed separately. The data from the TSPCK Instruments completed as pre- and post-tests were triangulated with data from the observations during the meetings, the completed CoRe and the interviews to describe TSPCK development. This part of the subsection will first describe the quantitative data analysis and then describe the qualitative data analysis.

(i) The Quantitative Analysis of the Post-test TSPCK Scores

The TSPCK instrument designed and validated in Phase I was also used to measure change of knowledge in Phase II of the study. The expectation is that, after an intervention, there will be both an improvement in the person's score and that previously difficult items in the instrument prove less difficult (Wright, 1996). The post-test instruments of the three Learning Study participants were scored using the TSPCK rubric (see Appendix 2). The post-test instruments were scored independently with one of the members of the PLC. We then came together to discuss the scores, and where they differed, we returned to the instruments to reach consensus. This was done to ensure trustworthiness of the scoring process.

Due to the small sample size in Phase II of this study, it was not possible to follow conventional methods of stacking the data, where each person appears twice to determine

changes in participants' understanding (Herrmann-Abell, Flanagan, & Roseman, 2013; Wright, 1996). The assumption was made that the three teachers participating in the learner study were still part of the target population, but the post-test scores represented different people after the intervention (Linacre, 2012). The post-test scores were therefore included in the original validation data file for the Rasch analysis with a slightly 'larger sample' of thirty-four teachers to determine new Rasch measures (Wright, 2003). The Rasch analysis was run on this larger sample, and the person means and items means were subjected to significance testing. Unfortunately, the data could not be racked in order to determine the impact of the intervention on item difficulty (Herrmann-Abell *et al.*, 2013; Wright, 2003). The pre-test and post-test measures from the Rasch analysis were used to determine the change in scores. This analysis is described in detail in Chapter 6.

(ii) The Qualitative Analysis of the Post-test Responses

The responses of each participant in the Learning Study to the items were also analysed qualitatively. The qualitative analysis of the instruments was used to determine the extent to which the teachers' responses changed. The transcripts from the pre-lesson interview, SRI, discussion meetings and the exit discussion were used to find supporting evidence to account for any changes in the responses to each item on the pre-test and post-test. Vignettes that describe the differences between the pre-test and post-test scores were compiled as a narrative analysis, or texts that are 'thematically organised by plots' (Polkinghorne, 1995). In this case, the plot was the development of teachers' TSPCK through participation in a Learning Study. Due to the collaborative nature of a Learning Study and the teams' personal interactions, a narrative analysis provides a richer description for the reasons any changes, or lack thereof occurred. For the narrative analysis, the vignette is written from the subjective viewpoint of myself as a participant observer, as Zeller (1995) recommends. Telling the story through the eyes of one of the participants shows that no account can be truly objective (Lelliott, 2008).

The narratives are written based on the following criteria (Dollard, 1935 in Polkinghorne, 1995). For this narrative analysis, these include:

- The cultural context in which the story is set, which in this case is the teachers' epistemological and self efficacy beliefs for teaching.

- Involves a main character or protagonist, in this case the teacher and the narrative focuses on the teacher's choices and actions, or response to the items.
- The main character has a history, which in this case is their response to the pre-test.
- The story that results from the narrative analysis is time-bounded, and presents enough detail to demonstrate that this is a unique description of the teacher's change in TSPCK.
- The outcome of the narrative needs to be plausible, believable and understandable with a clear conclusion, in this case the teacher's own plans for taking his learning beyond the PLC.

Lelliott (2008) suggests that it is important to highlight how the criteria listed above relate to this study's data sources. This is provided in Table 3.5 below.

Table 3.5: Relationship between criteria for a narrative and data sources

Criteria (Polkinghorne, 1995)	Data Sources
Cultural context	Beliefs questionnaire Self efficacy survey
Protagonist	Discussion meetings, pre-lesson interview, video stimulated recall interview
Protagonist's interaction with events	Post-test responses CoRe developed as artefact for another big idea
Protagonist's history	Pre-test responses to TSPCK instrument
Time bounded story	Discussion meetings, video stimulated recall interview and exit discussion

Chapter 6 provides a detailed account of how the narrative analysis, in the forms of vignettes, were constructed as a vehicle for describing the teachers' change in scores in the TSPCK instrument (Zeller, 1995).

(iii) Scoring the Self Efficacy Survey

The three teachers participating in the Learning Study completed the *Teachers' Sense of Efficacy Scale* survey developed by (Tschannen-Moran *et al.*, 1998). The scale includes three factors relating to self efficacy, namely efficacy in student engagement, efficacy in instructional strategies and efficacy in classroom management. Each factor has eight statements and the teachers rate themselves on a scale of 1, for low self efficacy to a scale of 8 for high self efficacy. The survey is included in Appendix 2. The scores were determined by adding up the numerical value for each statement per factor and finding the average for the three factors. This was used to get a qualitative sense of the teacher's own feelings towards

these three factors of self efficacy. The surveys were analysed independently by me and a colleague to ensure trustworthiness.

(iv) Analysing the Beliefs Questionnaire

The beliefs questionnaire, was first used in a written format by Mavhunga (2012) and was adapted from the epistemological beliefs interview schedule (Luft & Roehrig, 2007). The responses were coded using the belief maps developed by (Luft & Roehrig, 2007). These are included in the Coding Manual in Appendix 3. Each belief map consists of descriptors for different categories of beliefs. These include: (1) traditional; (2) instructive; (3) transitional; (4) responsive, and (5) reform-based. This was used to get a qualitative sense of the teacher's epistemological beliefs about teaching and learning. The written responses were analysed independently by me and a colleague to ensure trustworthiness. The results from this questionnaire were used to explain possible discrepancies in PCK development since beliefs act as filters and amplifiers for practice.

(v) Coding of the Planning and Discussion Meetings of the PLC

Data from the observations during the planning and/or teaching the lesson were transcribed and subjected to thematic analysis using *Atlas.ti*. The pre-lesson interview and post-lesson video SRIs and final interviews were transcribed and also subjected to thematic analysis. A coding manual was developed, extracts of which are shown in Figure 3.6 and the transcribed meetings were coded in *Atlas.ti*. Coding typically involves two operations, namely setting up the category sets to classify the data, as well as separating the qualitative data into units (Guetzkow, 1950). The categories were set up and labelled using letters of the alphabet to make selecting the codes in *Atlas.ti* more user-friendly. Figure 3.6 shows the codes used to categorise participation. The TPK&S model (Gess-Newsome, 2015) was then used to further categorise participation, according to aspects of the model as shown in Figure 3.6. Finally, the TSPCK model was used to further categorise TSPK[11] in the TPK&S model into the five components of TSPCK. The individual codes were then grouped into families as shown in Figure 3.6 which show the codes that make up the families of code for WDT and REP.

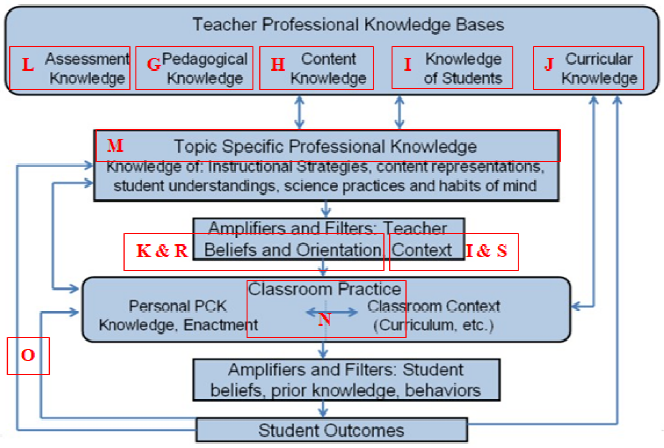
[11] The TSPCK model has been conceived as the vehicle for Topic Specific Professional Knowledge (TSPK) in the consensus model and TSPCK will be used when referring to topic-specific professional knowledge.

	CODE
A	Researcher (Stephen)
B	Supervisor Cycle 2 (R01:Maggie)
B	Supervisor Cycle 3 (R02:Ellen)
B	Supervisor Cycle 4 (R03: Sandra)
B	Support team member (Lerato)
C	Participant Cycle 2 (L01: Sipho)
C	Participant Cycle 3 (L02: Tendani)
C	Participant Cycle 4 (L03: Sizwe)

Notes:

1. The first cycle of the learning study was taught by the Researcher, hence the three participating teachers are indicated as Cycle 2, Cycle 3 and Cycle 4 based on the order in which they taught the lesson.
2. The codes R01, R02, R03 correlate to the supervisor of the participants labelled L01, L02, L03.
3. The names of the supervisors and the participating teachers have been changed to ensure confidentiality as stipulated in the informed consent letters signed by each participant.

Extract from coding manual showing codes used to categorise participation



The model of topic-specific PCK is viewed as the mechanism for the measurement and development of teachers' TSPK and forms part of theoretical framework for this study. Coding specifically for the TSPCK components served as the **fourth level of coding** in the meetings. In this model, content knowledge is transformed through five knowledge components.

Extract from coding manual showing the letter of the codes allocated to TPK&S model.

Code Family: 22: What is difficult to teach
Created: 2016-03-06 16:31:37 (Super)
Comment:
This family is liked to topic-specific PCK which is linked to Topic Specific Professional Knowledge. This family includes all aspects of what makes the topic of stoichiometry difficult for learners to understand and teachers to teach.
Codes (8): [M3: Abstract nature of concept] [M3: Different ways to calculate amount] [M3: Difficulty related to problem solving] [M3: Identification of difficult concepts] [M3: Linking levels of representation] [M3: Mathematical reasoning] [M3: Misconceptions affect understanding] [M3. Use of terminology]

Code Family: 23: Representations
Created: 2016 03 06 16:31:18 (Super)
Comment:
This family is liked to topic-specific PCK which is linked to Topic Specific Professional Knowledge. This family includes all aspects related to the three different levels of representation specifically related to teaching stoichiometry.
Codes (9): [M4: Macroscopic/experiment] [M4: Macroscopic/modelling] [M4: Macroscopic/demonstration] [M4: Submicroscopic] [M4: Symbolic/equations] [M4. Symbolic/periodic table] [M4. Use of analogy] [M4. Use of story] [M4. Using two/three levels of representation]

Extract from coding manual showing examples of families of codes set up in *Atlas.ti* for TSPCK components WDT and REP

Figure 3.6: Extracts from coding manual to illustrate the levels of coding and grouping of codes into coding families

The data from the PLC meetings were systematically coded in four rounds of coding. This was needed since the video-recorded meetings represented continuous observational data that is often difficult to categorise (Guetzkow, 1950). In the first round, the qualitative data was separated into 'people units', or who was speaking in the meeting, which was fairly straightforward. In the second round of methodical coding, the qualitative data was categorised into 'talk units', comprising aspects of discussion related to research and student performance. This included the results of the pre-testing and post-testing of students which is central to the planning of the lesson in a Learning Study. This round of coding was more difficult because the 'talk units' ranged in size from simple agreements to long monologues by the participants, and these talk units could be classified into different categories (Guetzkow, 1950). All other aspects of the discussion were categorised into 'talk units' that included input from the team related to planning and improving the lesson, debate and clarifying ideas and logistics for the Learning Study. These two coding units represented the categories related to the teachers' participation in the discussions related to the activities of the Learning Study.

The third and fourth stage of coding related specifically in breaking down the 'talk units' into smaller units. This was based on the object of learning, developing the teachers' TSPCK within the framework of teacher professional knowledge, specifically in the topic of stoichiometry. This multi-dimensionality of the category sets resulted in the double-coding or in some instances triple coding of the 'talk units' (Guetzkow, 1950). During the third stage of coding, the discussion was categorised into 'TPK&S units' based on the codes shown in Figure 3.6. Finally, during the last stage of coding, aspects of the discussion related specifically to TSPCK were coded according to the five components (Mavhunga, 2012), as well as aspects that highlighted the teachers' beliefs which were categorised according to the teacher beliefs outlined by Luft and Roehrig (2007). Coding for teacher beliefs was considered important as these can either amplify or filter how teachers learn in professional development activities (Gess-Newsome, 2015). Figure 3.7 shows an extract from *Atlas.ti* to illustrate the coding process. The extract is from the planning workshop where the teacher participants were introduced to TSPCK for the first time and the discussion is between me, the facilitator of the workshop, and the supervisors for each participant's research project who are experts in chemistry education.

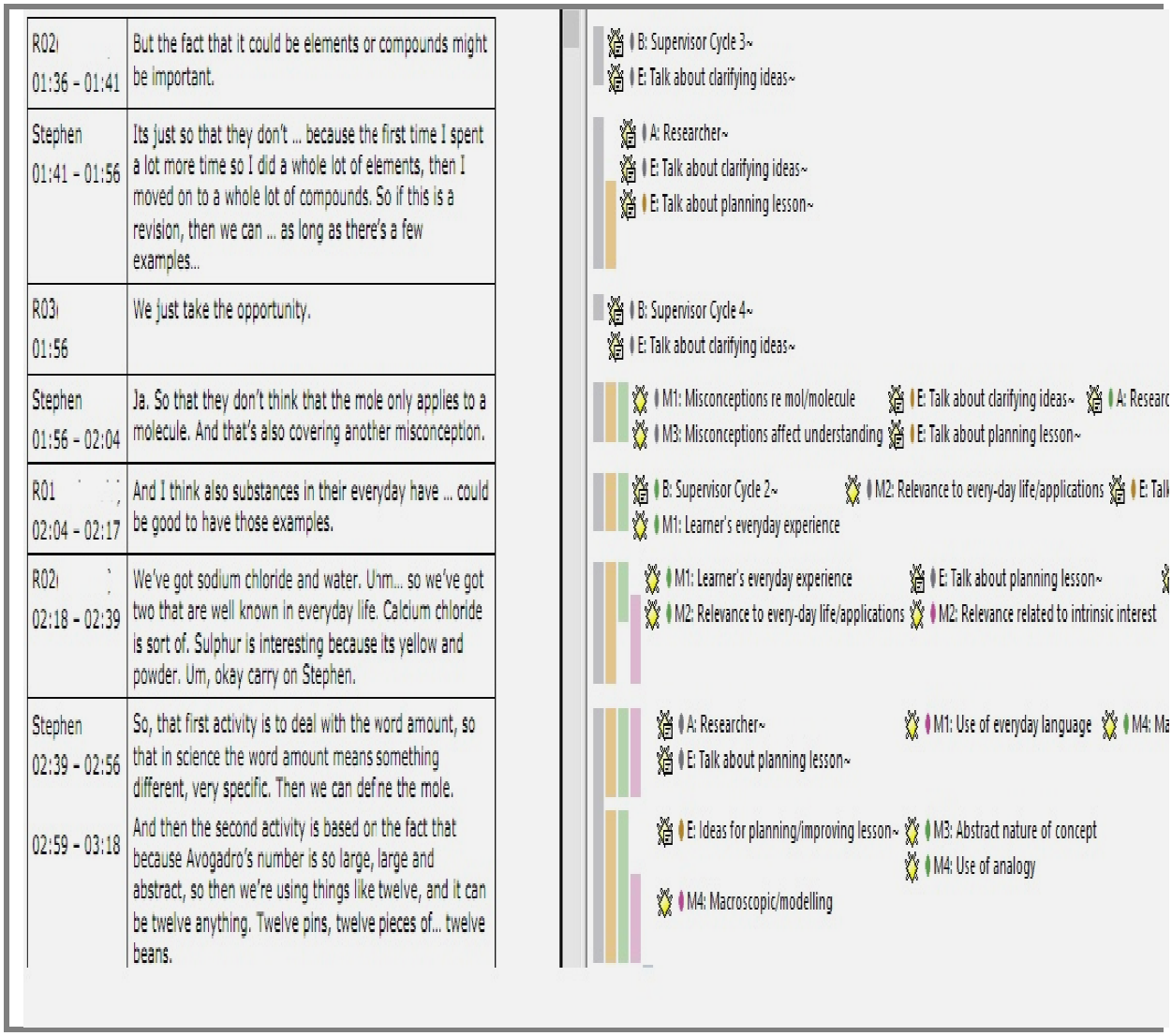


Figure 3.7: Extract from Atlas.ti to illustrate the coding process of the transcriptions of the PLC meetings

The above represents an in-depth coding of semi-structured discussion meetings. Developing the coding manual provided a means of standardising the units of texts (Campbell, Quincy, Osserman, & Pedersen, 2013). The manual, along with thirty randomly selected pages from the five sets of transcripts, was sent to a colleague whose research also involved the TPK&S and TSPCK models as part of her framework, to code. This represented just over ten percent of the transcripts and was done to determine intercoder agreement. Each of the codes was assigned numerical values since they represented nominal data in category units. These numerical values were captured in Excel spreadsheets, one spreadsheet for each category. These were then uploaded into the computer program *RelCal* to determine inter-coder reliability by calculating Krippendorff's alpha (Freelon, 2017). The latter is a value that determines the extent of agreement between two coders. It is expressed as a ratio in terms of

the number of disagreements in the coding where values greater than 0.8 are considered acceptable for drawing valid conclusions (Krippendorff, 2012). For each of the levels of coding for 'talk units', 'TPK&S units' and 'TSPCK Units', Krippendorff's alpha ranged from 0.822 to 0.843 (see Appendix 21).

The coded data was analysed in *Atlas.ti* in two ways. Firstly, the 'codes primary documents table' was used to generate the frequency of the different talk units to determine the extent to which the PLC engaged in talk about the specialised knowledge used to analyse practice (Hargreaves & Fullan, 2012; Reichstetter, 2006; Stoll & Seashore Louis, 2007). Secondly, the code co-occurrence table was used to determine each team members' contribution to the discussions. This analysis is discussed in Chapter 6.

Phase II Data Analysis: Impact of Learning Study on Enacted TSPCK

In order to determine the impact of the Learning Study on teachers' enacted TSPCK data was collected through observations as described earlier. Video-SRIs were also conducted with each teacher. The same protocols were followed with the teachers in the comparison group. This part of subsection will describe the data analysis used to determine the impact of a Learning Study on enacted TSPCK.

(i) In-Depth Analysis of Video-recorded Lessons

Lesson observations were conducted for the lesson taught by each of the teachers participating in the Learning Study. Ideally, to determine the impact of the Learning Study on enacted TSPCK, observing these teachers teaching before the Learning Study would have been preferable. However, there were a number of factors (outlined below) that made this difficult to accomplish. Therefore, the lessons of a comparison group were observed. The equivalence of the two groups of teachers was discussed in subsection 3.5.4.

(ii) Reasons for Observing the Learning Study group and Comparison group

Firstly, there were scheduling problems related to the very prescriptive operational curriculum, the what and when teachers teach in class (Mnguni, 2013). The topic of stoichiometry is taught in Term 3, towards the end of September in Grade 10 and in Term 2, towards the end of May in Grade 11. In addition to this, the research component of the two-year part-time M.Sc programme in which the three teachers were involved requires that the research project be conducted in the second year of the programme. The participating

teachers, therefore, had less than a year in which to conduct their own projects. In Chapter 5, a detailed description of the schedule of the Learning Study is outlined, with the first meeting happening in late May. Since the planned collaboration in a Learning Study takes considerable time (Pang & Marton, 2003), it was not feasible to observe the teachers before we began planning the lesson.

Secondly, it was decided that analysing previous lesson plans was not an effective way to gauge the impact of the Learning Study on enacted TSPCK. Although lesson planning is often considered as a core feature of effective teaching, it is often just a technical task to ensure effective classroom performance (Ashcraft, 2015; Rusznyak & Walton, 2011). The linearity of thinking demanded by most formats of lesson planning that provide ridged templates for lesson plans, do not encourage the creative, problem-solving aspects of planning and teaching (John, 2006). They also often limit the possibilities that the process of lesson planning offers, if the teachers do not plan specifically to provide a narrative of their pedagogical reasoning in articulating their content knowledge (Rusznyak & Walton, 2011). As experienced teachers who had completed their teacher training more than a decade ago, there was no guarantee that any lesson plans they had were anything more than a technical blue-print for action (John, 2006). Experienced teachers over time also tend to gradually store successful lessons as scripts that are retrieved when teaching and so might not have written lesson plans (Stender *et al.*, 2017).

Lastly, even among pre-service teachers who had specifically been taught the skills that allowed the pedagogical transformation of content knowledge, the number and quality of TSPCK episodes found in classroom enactment were notably better when compared to their lesson plans (van der Merwe, 2018). Therefore, because of the limitations, both in terms of time and the type of data that could be generated from lesson plans on the impact on classroom enactment from participation in a Learning Study, a comparison of observed lessons taught by experienced teachers who did not collaborate and who were not involved in the Learning Study was undertaken.

(iii) Identifying TSPCK Episodes

The nature and integration of the TSPCK components in the enacted lessons of the Learning Study group and the comparison group were captured through an in-depth analysis of the video-recorded lessons using the approach described by Park and Chen (2012). The TSPCK

episodes, as defined, required at least two components to be evident in the teaching segment. These were derived mainly from the video-recorded lessons, but as with the study conducted by Park and Chen (2012) complemented by the pre-lesson interviews, video-SRIs and the teachers' responses to the TSPCK instruments. The in-depth analysis was captured in table format with columns for the lesson segment, the time-frame from the videos for an episode and a description of the episode including what was said and done by the teacher from which the TSPCK components were identified and described (refer to Appendix 17 for a detailed account). The TSPCK episodes were then mapped in the table, with the TSPCK map being an analytical device (Park & Chen, 2012) to illustrate the frequency and interaction of the components. This is described in detail in Chapter 7. The score from the TSPCK enactment rubric, outlined at the end of this subsection, was also included in the table. Finally, comments and any supporting evidence from other data sources were included (see Appendix 20).

(iv) Construction of TSPCK Maps

The TSPCK maps were constructed from the summarised descriptions that identified the TSPCK components in an episode. Figure 3.8 shows a TSPCK map from the pilot lesson of the Learning Study. This example is being used because it has all five of the TSPCK components. It also shows that the interactions can be interwoven, where the teacher moves in and out of these components, using them together or in a linear sequence where one component follows another. The components are represented as circles, with interwoven interactions indicated by overlapping circles. Where one component is followed by another, an arrow is used to represent the directional flow. For simplicity purposes, the TSPCK components are abbreviated (Mavhunga, 2015). The abbreviations used are: LPK for learner prior knowledge, CSA for curricular saliency, WDT for what is difficult to teach, REP for representations and CTS for conceptual teaching strategies. For representations, to distinguish where the three levels of representation are used in chemistry, namely macroscopic, submicroscopic or symbolic, these are included in brackets under the abbreviation REP.

The context in which the presence of the TSPCK components emerged, which could be related to written planning in lesson plans or CoRes but in this case is related to classroom enactment, are in the rectangular block. Henceforth this teaching context is referred to as "the platform" (Mavhunga, 2015). Generally, the TSPCK component conceptual teaching strategies is often the most difficult item in the TSPCK instrument as it subsumes the other

components (Mavhunga & Rollnick, 2013). In the instrument, the item related to the conceptual teaching strategy, if mapped, mostly forms the platform. However, in classroom enactment where components are interacting, to avoid mistakenly considering an episode as a conceptual teaching strategy, CTS is included in the map in Figure 3.8 (refer to Appendix 17).

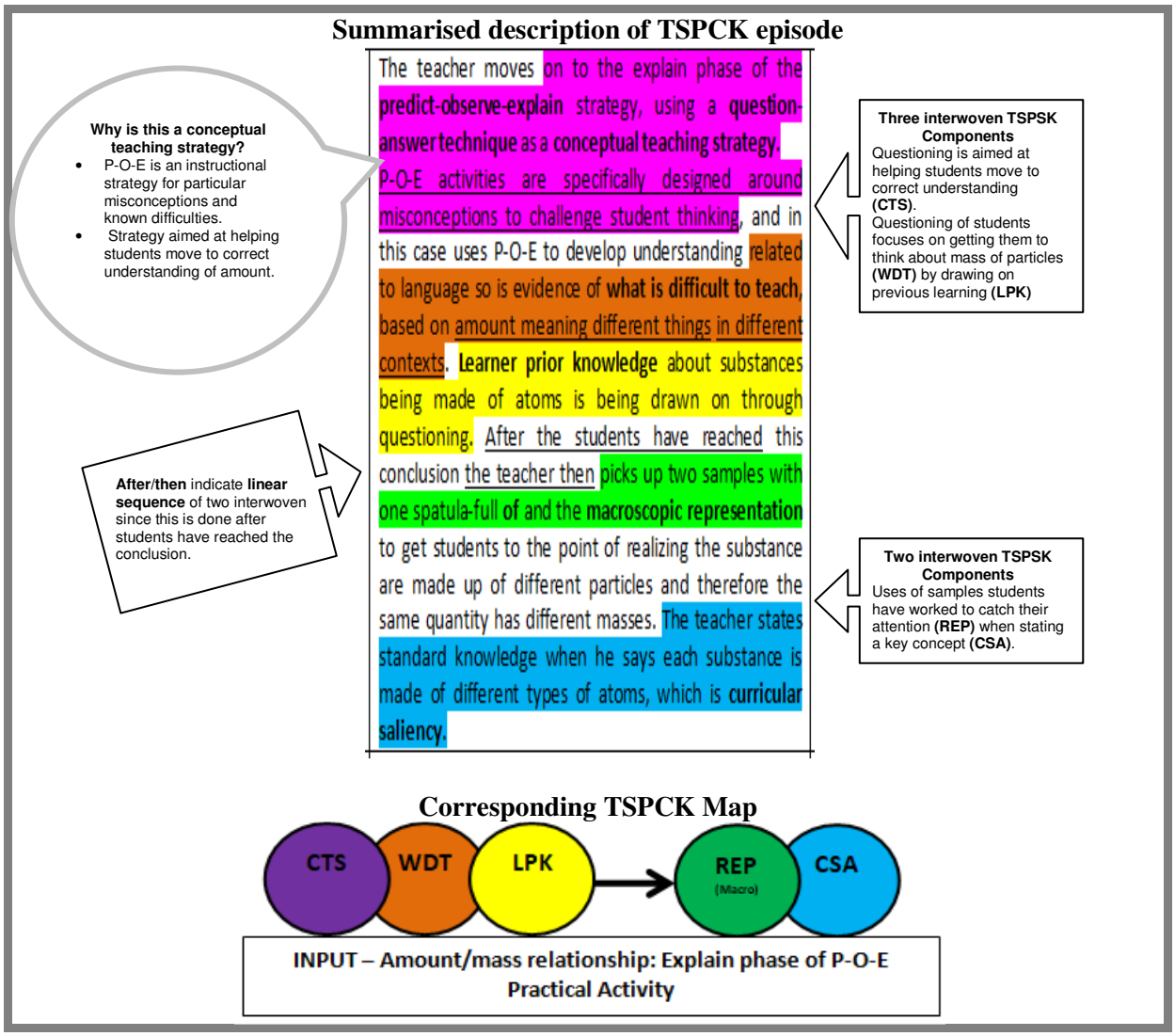


Figure 3.8: An example of a TSPCK map developed from a summarised TSPCK episode from the pilot lesson of the Learning Study

(v) Deciding on the TSPCK Map Platform

As has been mentioned, the context in which the presence of the TSPCK components emerged is referred to as the platform (Mavhunga, 2015). After the in-depth analysis of the video-recorded lessons of both the Learning Study group and the comparison group, it was evident that, although there was a difference in the quality and sequence of TSPCK components, the platforms seemed too varied to make comparisons. Firstly, the Learning Study lesson occurred in two sessions on the same day as a revision lesson, whereas the comparison group taught lessons introducing stoichiometry during fixed periods during the school day. Hence any attempt to describe the impact of the Learning Study on classroom enactment seemed intuitively untrustworthy, due to these differences. This dilemma was solved through my own teaching of planning effective lessons. One of the ways to plan effective lessons, commonly called 'the seven step lesson plan' (Wolfe, 1987, p. 70) is based on including seven basic elements teachers need to consider when planning. These planning elements are not a rigid formula for lesson planning, but are research-validated instructional elements that are present in effective lessons (Wolfe, 1987). It was for this reason that these were used as the platforms for the TSPCK episodes and formed part of the theoretical framework of this study (see Section 2.6).

In all the lessons, six of the seven elements included in this model for lesson planning were present. In the Learning Study lesson, there was no independent practice, in which students complete a task on their own with no assistance from the teacher, which includes homework (Hunter & Russell, 1976). Each lesson element includes a range of sub-skills, techniques and methods and these served as the contexts for the platforms of the TSPCK maps. The different lesson elements and the set of sub-skills, techniques and methods that make up the teacher tasks that comprise these elements are summarised in Table 3.6 on the next page.

For the element related to input and modelling, the aspects of the big idea related to the mole were also included in the platform. These included: (i) the mole as the SI unit for amount of substance, (ii) the mole as a counting unit of elementary particles, and (iii) molar volume. A classroom enactment rubric developed and validated by Miheso and Mavhunga (2018) was used to assign scores to the TSPCK maps and this is briefly described in the next subsection. The classroom enactment rubric is described in detail in Chapter 7.

The seven lesson elements identified above, six of which are included in Table 3.6, considered research-validated practices used to promote student learning, were selected since they represent elements for planning, regardless of what form the instruction takes (Wolfe, 1987). This was considered appropriate since these lesson elements provided a context in which to investigate the natural interactions of the TSPCK components for all six teachers, despite the highly varied lessons. The elements used that were present in all the lessons observed include: anticipatory sets, objectives, input, checking for understanding, guided practice and closure (Hunter & Russell, 1976). Independent practice typically relates to giving students homework in order to consolidate what is taught in class (Hunter & Russell, 1976) and did not provide a context in which the interactions of TSPCK components emerged. The six elements that did provide the teaching context from which the interaction of TSPCK components emerged are described below as elements one to six in Table 3.6.

Table 3.6: Lesson elements and teacher tasks of each element used to as TSPCK Map platforms

Lesson element	Teach tasks (sub-skills, techniques and methods)
1. Anticipatory set	• Activity to focus students attention • Linking to students experience • Tapping into learner prior knowledge • Recapping work covered in previous lesson/activity • Motivating learning (linked to application of stoichiometry)
2. Objectives	• Purpose of the lesson • Listing or describing lesson objectives
3. Input and modelling	• Teaching or introducing main concepts or providing information from textbooks/audio-visual information/activities • Re-wording or re-explaining important concepts • Emphasizing important information • Using examples to highlight or illustrate a concept • Teacher demonstrations • Experiments
4. Checking understanding	• Formative evaluations or asking students questions with feedback • Summarizing information • Responding to student questions • Re-explaining concepts based on observing/reaction of students • Re-teaching a concept
5. Guided practice	• Student discussion with feedback • Solving problems with feedback • Worked examples
6. Closure	• Final summary of the lesson • Extension of thinking • Linking to previous or next topic

The anticipatory set includes motivating learning and outlining the importance of learning a concept, which is an important aspect in the Tullberg *et al.* (1994) teaching model for teaching the mole. It relates to the TSPCK component of curricular saliency (refer to Chapter 2). The anticipatory set can also include focusing on learner prior knowledge. The second

element relates to stating lesson objectives. The third element is input, which includes teaching the main concepts, emphasising clear explanations, using examples and/or diagrams and inviting active student participation. The fourth element, checking for understanding, includes interpreting student reactions and frequent formative feedback, such as responding to student questions. The fifth element includes providing guided practice which includes students answering questions, discussing concepts or solving problems, with feedback given. The sixth element, closure, includes a final summary of the lesson. To reiterate, these lesson elements, an aspect of pedagogical knowledge which is one of the professional knowledge bases for teaching, provided the context in which to examine the nature of the interactions of the TSPCK components.

In the Learning Study lessons and the comparison lessons, the input element related the big idea on the mole concept. This big idea states "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 be used to help count elementary particles that make up substances". Furio *et al.* (2000) highlight that there are three important relationships related to understanding the mole concept, and these three relationships are captured within the big idea (refer to Appendix 6). Understanding these relationships is therefore essential for students to understand the mole concept. The input lesson element was therefore further subdivided into input relating to each of these relationships between amount of substance, mass, volume of gases and number of particles. Firstly, as input related to explaining the mole concept including the mole as the SI unit for amount of substance and its relationship to the mass of a substance. Secondly, input related to connecting the macroscopic property of mass with the microscopic property of matter, that allows the counting of particles. Finally, input related to connecting the macroscopic property of molar volume of gases with the microscopic property of matter. Figure 3.9 provides a summary of how the interacting TSPCK components were assigned to the lesson elements and how the input element was further categorised to capture the teaching of the three relationships students need to learn to understand the mole concept.

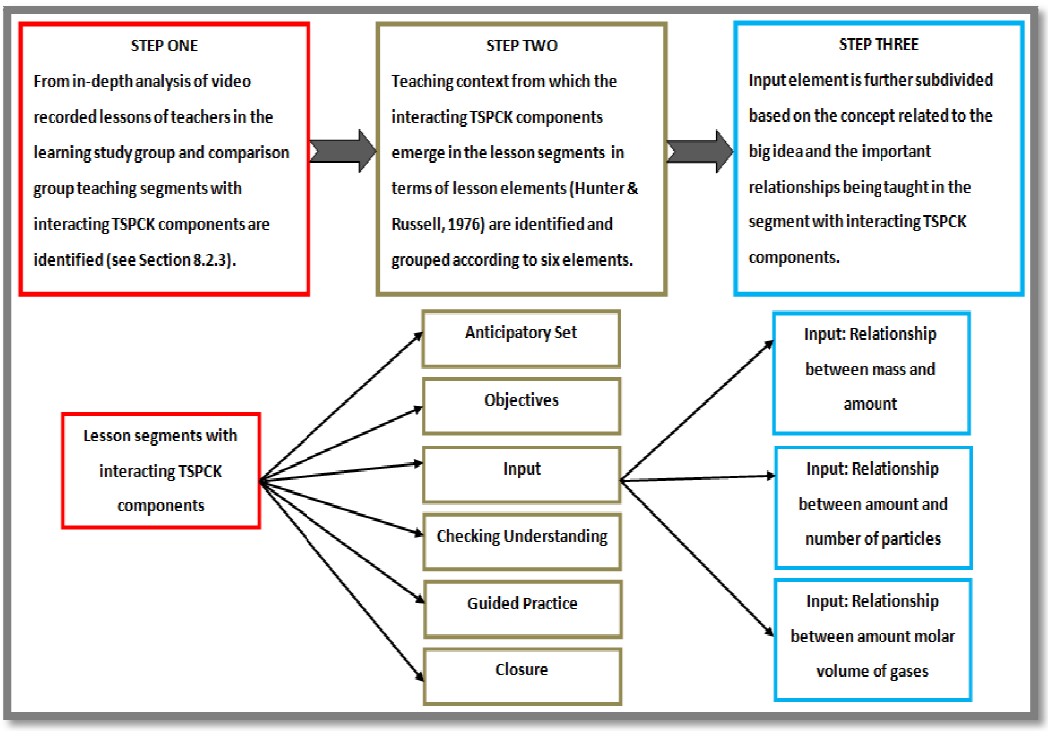


Figure 3.9: Summary of how lesson segments with interacting TSPCK components were assigned to teaching contexts

(vi) Analysis of the TSPCK Episodes

The TSPCK episodes for the Learning Study group and the comparison group were analysed in various ways and this analysis is reported on in Chapter 7. Firstly, the frequency of TSPCK episodes in the lessons taught by each participant were identified, analysed and categorised using an enactment rubric developed by Miheso and Mavhunga (2018). The rubric is included in the coding manual in Appendix 3. It consists of a set of criteria that are specifically used to distinguish the quality of the TSPCK episodes in terms of the number of TSPCK components and the interaction amongst these components (Miheso & Mavhunga, 2018). The TSPCK episode maps were categorised as basic, proficient or sophisticated and used to develop TSPCK action profiles to provide an overview of the total number of types of TSPCK episodes as categorised by the TSPCK enactment rubric.

The number of TSPCK episodes per quality category were captured on an *Excel spreadsheet*. These were tallied in order to capture the number of basic, proficient and sophisticated TSPCK episodes. The interconnectedness between the TSPCK components in the various TSPCK episodes were also enumerated and mapped to determine the integration of TSPCK components in a teaching segment that comprised a number of different episodes (Park & Chen, 2012). A similar approach was used to develop a TSPCK event map (refer to Chapter

7), similar to the PCK map used by Park and Chen (2012). This method was used to explore the interconnectedness between the different TSPCK episodes in teaching a concept. The lesson elements were used as a means to define segments of time for teaching a particular concept related to the mole. This analysis is also described in Chapter 7.

As has been mentioned, the TSPCK enactment rubric was used as a scoring tool for observable differences that allowed the TSPCK episodes to be rank-ordered (Lammers & Badia, 2004). These ordinal scores were therefore not based on subjective categories and can easily be transformed into numerical scores, since the rubric categories were simply used as rating scales and the rank order was averaged (Wu, 2007). Therefore, average scores were obtained for each lesson element. This was done by finding the sum of the scores for each teacher in the Learning Study group and the comparison group and dividing the total scores by the number of TSPCK episodes in that lesson element. The average score for the three teachers for each lesson element in the Learning Study group and the comparison group were subjected to a *Wilcoxon signed ranked test* to determine if there was a significant difference between the lessons taught by each group of teachers.

This section has described how the data from phase I and Phase II of this study were analysed. The remainder of this chapter focuses on the validity and trustworthiness of the data, ethical considerations and the limitations of this study.

3.8. Validity and Trustworthiness

According to Teddlie and Tashakkori (2009), the quality of data in mixed methods research is determined by the quality of data collected in the quantitative and qualitative strands, since if data from the individual strands are valid, the mixed methods study will have a high quality. As the research design is a multiphase design, the different phases are described below.

3.8.1. Phase I: Exploratory Sequential Design

According to Pesudovs, Burr, Harley, and Elliott (2007), any study that describes the development of an instrument needs to state the specific construct the instrument intends to measure, and the intended population of the study. They also report on a number of issues to ensure the validity of the instrument. For example, translational validity relates to how well the construct, in this case, TSPCK, being measured, is represented by the instrument and encompasses face validity and content validity (Pesudovs *et al.*, 2007). Face validity refers to

the extent to which the items in the instrument, or the instrument as a whole, measures what it purports to measure through being representative of the appropriate content or task, and includes how the items are phrased (McMillan & Schumacher, 2010; Pesudovs *et al.*, 2007). Items should be clear, unambiguous, kept brief and must minimise potential errors from respondents (Bell, 2005; Pesudovs *et al.*, 2007). Clarification of the content area is also important for face validity (Pesudovs *et al.*, 2007). The reference team selected for this purpose ensured these aspects of validity.

Content validity is the extent to which the items in the instrument reflect the entirety of the concept being measured (Pesudovs *et al.*, 2007). To ensure that there is a good breadth of relevance of instrument items, Pesudovs *et al.* (2007) suggests three approaches. These include obtaining sample statements and experiences from individuals in the target population, which is part of the mixed methods research design for Phase I. The second approach suggests obtaining opinions from experts in the field (Pesudovs *et al.*, 2007). For this phase of the study a reference team consisting of experts in chemistry education and TSPCK was used to ensure content validity. The members of the reference team are involved in pre-service chemistry education and in a project to measure TSPCK. Item generation typically results in the production of a large number of items and a process of item reduction was required, the third approach to ensure the breadth of instrument items (Pesudovs *et al.*, 2007). This was accomplished through the use of a pilot instrument with a respondent population that is broad and representative of the target population (Pesudovs *et al.*, 2007). Finally, in order to ensure construct validity, unidimensionality statistical methods were used to justify the items (unidimensionality describes how the items included in the instrument fit with the underlying construct being measured) (Pesudovs *et al.*, 2007). The statistical methods used in the analysis to ensure the construct validity of the instruments included Rasch analysis of the scores. Another way to address issues of validity within this study is to ensure that care is taken in the presentation of discussions related to the development of the TSPCK instrument and CK instrument, thus ensuring the accuracy of the factual account of the process - descriptive validity (Onwuegbuzie & Johnson, 2006). The various appendices on instrument design attached to this thesis provide just such a description. This subsection has outlined the process followed in the design of the instruments to highlight that the data collected is trustworthy. A complete account of the design and validity of the instruments is reported on in my M.Sc Research report (Malcolm, 2015).

3.8.2 Phase II: Convergent parallel design

Since this phase consists of collecting qualitative and quantitative data separately, the methods to ensure validity for each strand are discussed separately.

(i) For the Quantitative Method

The quantitative method in this phase of the study is used for the measurement of the development of TSPCK and CK performance scores to answer the question: do these scores differ significantly as a result of the intervention? Statistical analysis of the means of the Rasch analyses were used to indicate that the assumption that the post-test scores represented new people of the same target population was valid. This was to ensure that when the data was stacked with the participants' pre-test and post-test scores for measuring changes between quantitative scores of transformed data, reflecting the quality of the observed PCK before and after the professional development opportunity could be unambiguously attributed to the intervention (Wright, 2003). Traditional internal and external validity issues for quantitative studies were also observed.

(ii) For the Qualitative Method

Trustworthiness is a concept introduced by Lincoln and Guba (1985) to represent many of the quality measurements in qualitative research. Trustworthiness for the qualitative strand of this phase of the study was improved through triangulation of different data sources. A reflective journal recording a variety of information on a daily basis, including field notes on classroom observations was kept to provide information on the events in the classroom, and the method and thoughts of the researcher. This enables thick qualitative descriptions of the study to be made. These, in turn, improve trustworthiness. Internal validity was established by controlling particular threats that might supply alternative explanations for studied outcomes. External validity, on the other hand, reflects the degree to which study results could be generalised to different places or persons. According to Creswell (2012), triangulation is essential to enhance the accuracy of any qualitative study. The interviews and video-SRIs, the observation data of the lessons and responses from the teachers' beliefs questionnaire were corroborated from the different sources. Member checking with the participants is also essential since the vignettes include descriptions of what occurred in the PLC. Member checking ensured that these vignettes are complete and realistic, and include interpretations

that are fair. The hermeneutic unit (HU), which provides the data structure for this study (Friese, 2013) is provided on a CD attached to this thesis. The HU provides the audit trail for this study as it includes all the transcripts of the planning and discussion meeting, the interviews, code families and memos I made while coding the data in *Atlas.ti* (Lelliott, 2008). Extracts from the HU are included in Appendix 22.

3.9. Ethical Issues

The participants were informed prior to the study about the purpose of the study through an information letter that highlighted all issues concerning voluntary participation, confidentiality and anonymity, and those who participated were required to sign an informed consent declaration. Permission from both the school and parents was sought, to work with students. Parents and students were informed of the general purpose of the study in writing and informed consent forms were signed by both parents and learners. At all stages, before administering the developed TSPCK instrument and CK instrument, participating in the Learning Study or agreeing to allow classroom observations, video-recording or audio-recording, individual participants were informed about the purpose of the study. During any form of recording participants were informed that they could request not be recorded and that, in interviews, they did not have to answer all the questions and could stop at any time. They were also informed about the guarantee of anonymity and that information collected during the study was confidential, they would not be harmed and that the study would not jeopardise their job or result in the loss of their job due to their participation. They were also informed that they could withdraw from the study at any stage if they so wished. The participants were informed that the data collected during this study would be used for research purposes and reported on in a research report or thesis, and possibly in conference proceedings and journal articles, due to the interest in PCK as a construct to improve teaching as an activity and a profession, improve teaching practice and thereby improve learner understanding. All information letters and informed consent forms are included in Appendix 1.

Once participants, both teachers and students, completed the instruments, the cover sheets that captured demographic information was removed after each participant's scripts had been assigned with a unique identifying code and pseudonym, thereby ensuring anonymity. For ease of analysis, the instruments were scanned into an electronic format and stored on a

password protected computer. The use of pseudonyms, or unique identifying codes, was also used to ensure the validity of the results so that the various instrument responses could be matched and analysed. In addition, all cover sheets were kept in a securely locked cupboard. By signing the consent forms, participants indicated their willingness to participate on a voluntary basis in the study, but had the freedom to withdraw from the study at any stage. Ethics clearance for this study was obtained through the ethics application procedure instituted by the University through which this study was conducted and permission was granted from the Department of Basic Education to work in schools. These are included in Appendix 1.

For Phase II of the study the same ethical considerations were afforded the teacher participants and the expert members of the PLC. Throughout this study, the names used are pseudonyms and the names of the schools are purely fictional to ensure anonymity. Where photographs or screenshots have been used to show teaching, every effort was made to not include photographs from which participants could be identified. If this was not possible, *Adobe Photoshop* was used to blur the faces of the participants.

Another important ethical consideration to take into account was that the three teachers participating in the Learning Study were enrolled as M.Sc students at the university. Their participation in this study was therefore collaborative as it was linked to their own research projects and we therefore shared a common goal (see Chapter 5). Due to the fact that they were working to a tighter research deadline every effort was made to ensure that aspects of data collection for this study were timed around the teachers' schedules. Therefore, the video SRIs and exit discussion were only conducted after they had finalised the final draft of their own research reports. Their participation was in no way linked to the final outcome of their research projects as these were assessed by independent examiners as per university policy.

3.10. Reflexivity

Lelliott (2008) and Mavhunga (2012) both explain that reflexivity is the extent to which a researcher is aware of his or her own assumptions or biases in extracting meaning from data collected during the research process. According to Finlay (2002), however, reflexivity can be understood in a multitude of ways. For example, it can be understood as a confessional account of methodology and my own personal assumptions or biases. Alternatively, it can

also mean exploring the dynamics of the researcher-participant relationship. For this study, both of these understandings of reflexivity are important.

3.10.1. Assumptions and Biases

In Chapter 1 of this thesis, I outlined my positionality with which I approached both the design of the instruments and examining classroom enactment. During the analysis of the data, I attempted to be aware of this positionality in both the data collection and data analysis. During the activities of the PLC, I kept a reflective journal, extracts of which are included in Appendix 20. During the analysis using *Atlas.ti,* I also recorded memos that show my thoughts and interpretations. The HU is provided on a CD attached to this thesis. More importantly, however, for this study are the dynamics of the researcher-participant relationship, since I was involved as a participant observer and my role is described in the next subsection.

3.10.2. My Role as Researcher

A PLC is viewed as a place of and for relationships, amongst other things (C. Mitchell & Sackney, 2007), but I was the only member of the PLC with no pre-existing relationship with the teacher participants. The purpose of this research, the conceptualisation of the study, invited participation of the participating teachers through negotiation with their respective supervisors and the basic project design gave me clear 'ownership of the project' (Jaworski, 2008, p. 312). However, since each of the participants was researching their own TSPCK and/or classroom enactment as part of their Masters' research project, they were more than just participants inside schools engaged in action and my role needed to be more than just a researcher engaged in an inquiry since we were engaged in jointly defined work (Wagner, 1997). As a researcher, I was attempting to investigate what happens in the classroom, working with teachers attempting to develop their professional practice, which required collaborative classroom research and sharing ideas through reflective discussion organised around classroom events (Cole, 1989).

My key role, therefore, was to set up and sustain the PLC, help maintain focus on the theoretical framework of topic-specific PCK and student learning in the reflective discussions and re-articulate goals based on team member contributions as a facilitator (Brodie, 2013; Brodie & Shalem, 2011). As a facilitator, my aim was to ensure a shared understanding

between the participating teachers and myself as researcher of our separate but complementary research enterprises to stimulate change in classroom enactment in what Wagner (1997) refers to as a clinical partnership.

A clinical partnership, despite being cooperative, still meant that, as a researcher, I would be working outside the schools to help practitioners improve their own effectiveness. However, based on the initial measurement of teachers' TSPCK in stoichiometry in Phase I of this study, and a review of the literature on the teaching of stoichiometry, teachers tend to focus on the algorithmic aspects rather than on conceptual understanding. Although, as the facilitator of the PLC, it was key to bring this knowledge and expertise to the group (Brodie, 2014), my concern was that the participants' expectations of my role would be to lead the developmental activity (Jaworski, 2008). For teachers to learn new ways of teaching, shared participation, in authentic activities like planning a lesson, is essential (Foulger, 2005). In order to facilitate this, with the hierarchy already present in the team, due to my ownership of the research design and the hierarchical demands of schools where teachers are often discouraged from sharing educational practices and collaboration, there was a need to create some kind of sharing of power and responsibility (Botha, 2012; Jaworski, 2008).

Feelings of interdependence among team members in a PLC is central for effective collaboration (Bolam *et al.*, 2005). The first aspect of that interdependence, which is a major attribute of effective PLCs, is collective inquiry through questioning, exploring, investigating and researching practice (Jaworski, 2008; Reichstetter, 2006). In order to develop the respect and trust of the participating teachers that were expected to accept feedback on their classroom enactment, a more interactive form of cooperation was required to help facilitate the participants' emerging inquiry into their own teaching (Hord, 1997; Jaworski, 2008; Wagner, 1997). So in order to build the feelings of interdependence, through a more interactive collaboration and reflexive inquiry, my role would not only be that of researcher, but as a researcher-practitioner participating through action and reflection of my own teaching practice in a co-learning agreement (Jaworski, 2008; Reichstetter, 2006; Wagner, 1997).

Therefore, my role was not only as a facilitator of the PLC, but a colleague sharing my educational practices and doing research with the participants rather than about them, as a means to encourage the participants to do the same and develop the respect and trust needed for an effective PLC (Brodie, 2013; Hord, 1997; Yorks, 2005). This therefore linked the

participants and me as a researcher in a subjective relationship which is the essence of good qualitative data in order to provide rich descriptions of the contexts and experiences in the PLC (Toma, 2000).

3.11. Reflections

In qualitative research, the researcher becomes the instrument for research since a mixed methods study has a qualitative component; it relies largely on the personal activities and outlook of the researcher. To avoid this, the methods followed were fully described and include interpretations of participants in the Learning Study, or of the observed lessons to mitigate any bias or inadequacy. In each data analysis chapter, where required rich descriptions are provided to expand on the descriptions provided in this chapter. Due to the fairly small sample size in Phase I and the selection of cases from this sample for Phase II and the focus on one topic in chemistry, namely stoichiometry, this study is unable to claim generalisability. My role as a participant observer means that the data provided in the subsequent chapters needs to be viewed in this light as a limitation for the study. This is discussed in more detail in Chapter 8.

Since PCK is considered personal and therefore unique to a particular teacher based on their teaching context and the school where they are employed, it could therefore only represent those teachers who participated in the study. However, this study contributes substantially to the body of knowledge on the development of PCK, especially in practising teachers and the enactment of the collective PCK evident in a PLC in the classroom, particularly related to the construct of topic-specific PCK. Student outcomes feed back into classroom practice, hence the need to administer the pre-lesson and post-lesson diagnostic tests to learners. However, this study is limited to investigating TSPCK development and enactment in the classroom, without investigating the possible impact on student outcomes of collabrative planning. This chapter has provided a description of my research design and data collection methods, in order to provide a full picture of how the research was conducted. Since this study was conducted in two phases, the next chapter focus on measuring the quality of teachers' TSPCK, since the results impacted on the focus of the Learning Study as a professional development activity, which is described in Chapter 5.

CHAPTER FOUR

The Quality of Experienced Teachers' TSPCK and CK as Measured by the Developed Instruments

This chapter provides an overview of thirty-one experienced Physical Science teachers' responses to the TSPCK Instrument and the overall performance in the Content Knowledge Instrument. Firstly, an overview of the teachers' general performance in all five of the TSPCK components is provided. The overview provides a qualitative description teachers' TSPCK. Secondly, this chapter provides insight into the in-depth qualitative analysis of the responses to one of the TSPCK components, conceptual teaching strategies, which subsumes all the other components. The teachers' responses are broken down and described. Thirdly, the teachers' Rasch measures for the TSPCK Instrument are examined to highlight how the scores speak to the level of integration between the components. This chapter also examines the teachers' CK scores and the relationship between TSPCK and CK. In addition, this chapter also provides an overview of teachers' conception of the mole, as it is said to influence their teaching strategies. From the above descriptions, a pattern of groupings emerged and is identified, and the teachers are profiled based on their teaching strategies, CK scores and conceptions of the mole. These profiles were determined empirically through cluster analysis. A description of these profiles is provided at the end of the chapter.

4.1. Introduction

According to Nilsson and Vikström (2015), teachers can develop their professional knowledge by focusing on specific science content and researching their own practice. Best practice for professional development includes, amongst others, that teachers' knowledge and skills should increase, that they use this new knowledge to improve the content and pedagogy of their instruction and that these instructional changes foster student learning (Desimone, 2009). Since the aim of this study was to investigate the impact of a Learning Study on professional learning, the baseline quality of practicing teachers' current knowledge needed to be determined before embarking on the task of constituting a Professional Learning Community and undertaking a Learning Study. The design and validation of instruments to

measure the quality of thirty-one experienced Physical Science teachers' TSPCK and CK in stoichiometry was undertaken as part of my Master's research (Malcolm, 2015)[12]. This chapter focuses on investigating the quality of the responses from the validated instruments and this investigation helped mould the professional learning activity described in the next chapter.

Firstly, this chapter outlines the scoring process for the TSPCK instruments. The scores were subjected to Rasch analysis using *Winsteps Ministeps* to determine person measures based on the responses to the instruments for the sample of 31 teachers. An in-depth qualitative analysis of the data from the instruments was conducted. This chapter therefore speaks to the first part of the research question, determining the baseline quality of experienced teachers' TSPCK and CK in stoichiometry. In this chapter, the data from the thirty-one teachers' responses to the TSPCK Instrument and CK Instrument will be investigated. Firstly, a qualitative analysis of the item response data was conducted to describe the quality for each of the components of TSPCK. For the teachers' TSPCK quality is defined in terms of the TSPCK rubric descriptors, which are discussed in the next section and the Rasch measure which is reported on in this chapter. This chapter reports on the overall performance of the teachers in all five TSPCK components and provides a more detailed account of only one component, namely conceptual teaching strategies (CTS). This component was selected as this is the component around which the lesson was planned in the PLC discussions (described in Chapter 6). The analysis of the other components is shown in Appendices 12 and 13. This chapter also highlights some of the limitations of using only the TSPCK Instrument to measure PCK (Morrison & Luttenegger, 2015). During this study three teachers who completed the instrument were observed teaching stoichiometry lessons in order to gauge the baseline implementation of teachers' enacted TSPCK in practice.

Secondly, the CK Instrument was used to determine the respondents' conception of the mole, since it has been argued that a conception of the mole that is consistent with the SI definition is required for effective teaching (Staver & Lumpe, 1993; Strömdahl *et al.*, 1994; Tullberg *et al.*, 1994). Thirdly, since CK has been described as a precursor for developing PCK (Rollnick *et al.*, 2008), it is important to explore the level of Physical Sciences teachers' CK in

[12] The report on the Master's project describes the validation for a sample of 20 teachers. Based on the examiner's report this sample was increased to 31 teachers. The validation for the larger sample is included in Appendix 8.

stoichiometry, in order to attempt to establish if there is a relationship between the measured TSPCK and CK. This chapter only focuses on the overall scores. Analysis of the responses is described in Appendix 14. Finally, from the qualitative analysis of the responses, teacher profiles for the sample of teachers, determined empirically through cluster analysis and based on their responses to the instruments, are described.

4.2. Scoring the TSPCK Instruments

The items in the developed TSPCK instrument were scored using a rubric as mentioned in Chapter 3. The rubric is described as a set of criteria used to measure a teachers' level of PCK (Park *et al.*, 2011). The TSPCK rubric was adapted from a study conducted by Park, Jang, Chen, and Jung (2008) to measure PCK. Mavhunga (2012) adapted the rubric for use in scoring responses to a TSPCK instrument in chemical equilibrium, where the rubric was shown to be able to 'reliably measure the specific qualities of PCK to evaluate the whole construct' (Ndlovu, 2014, p.41). The TSPCK rubric, with minor adaptation has been successfully used to measure these qualities in the topics of the particle nature of matter, electrochemistry and organic chemistry (Ndlovu, 2014; Pitjeng, 2014; Vokwana, 2013). The rubric consists of a four-point scale from 1, representing limited PCK to 4, representing exemplary PCK, to convert written responses to ordinal scores for analysis. Each level in the rubric is therefore a description of the quality of teachers' TSPCK for the five components of TSPCK. Each rating scale within the rubric listed descriptors, or criteria, for the five knowledge components that comprise the construct of TSPCK. The scoring process was also iterative as refinements needed to be made to the scoring process and to the criteria in the rubric because of the algorithmic nature of the topic of stoichiometry. In the studies mentioned above where the rubric was used, the conceptual teaching strategy scored teachers who used macroscopic representations as only having limited TSPCK, and those who used symbolic representations as exhibiting basic TSPCK. However, when teaching stoichiometry most teachers only use symbolic representations and not macroscopic representations. In the initial scoring the rubric had not been adapted to take this distinction into account. Therefore the instruments were rescored. The descriptors in the TSPCK rubric used in this study illustrated progression from one response category to another (refer to Figure 4.1). Scoring the questions singly allowed both analysis and development of insight into the trends of choices made by the respondents. The criteria for the knowledge category conceptual teaching strategies are shown in Figure 4.1 on the next page.

CODE:	Rubric for quantifying PCK – based on Components of Topic-specific PCK				Score	
	Limited (1)	Basic (2)	Developing (3)	Exemplary (4)		
Teaching strategies	▪ No evidence of acknowledgement of student prior knowledge and misconceptions. ▪ Lacks aspect of curriculum saliency. ▪ Use of representations limited to symbolic representations with no linking of explanatory notes. ▪ Activities are largely teacher-centred.	▪ Acknowledges student misconceptions verbally with no corresponding confrontation strategy. ▪ Lacks aspect of curriculum saliency. ▪ Use of symbolic **and/or** other representations with no linking explanatory notes. ▪ Limited involvement of learners.	▪ Overall strategy workable. ▪ Considers confirmation / confrontation of student prior knowledge and / or misconceptions. ▪ Considers at least one aspect related to curriculum saliency: sequencing or what not to discuss yet or emphasis of important concepts. ▪ Uses at least two different levels of representation to enforce aspect of concept with explanatory notes linking the representations to the aspect(s) of concept being considered. ▪ There is evidence of encouraged learner involvement.	▪ Overall excellent strategy to teach required concept. ▪ Considers confirmation / confrontation of student prior knowledge and / or misconceptions. ▪ Considers at least two aspects related to curriculum saliency: sequencing or what not to discuss yet or emphasis of important concepts. ▪ Uses macroscopic, visual / symbolic and sub-microscopic representations to enforce aspect(s) of a concept with explanatory notes linking the different kinds of representations to the concept being considered. ▪ Highly learner centred lesson.		

Figure 4.1: An extract from the TSPCK rubric modified for this study

Since the scoring process required scores to be allocated based on written responses and matched to criteria in a rubric, there was a need to ensure that any possible bias in the scoring process was negated (Creswell, 2012). This was done by two independent peers, both with experience in the field of PCK. Three respondents' instruments were rated and any differences in scoring were negotiated and reconciled and either changed or retained. The agreement rate for these overall scores was determined and expressed as a kappa index, determined using *Fleiss' multirater kappa calculator* (Chang, n.d.). Randolph (2005) states that the Fleiss' multirater kappa index is the most appropriate to use to determine interrater reliability for validity studies. The kappa index was calculated at 0.7602 at a 95% CI (included in Appendix 21), indicating a substantial agreement for interrater reliability (Landis & Koch, 1977). In the next section the general performance in the TSPCK instrument of the 31 teachers is discussed.

4.3. General performance of the Teachers in the TSPCK Instrument

The validation process of the TSPCK Instrument provided clear statistical evidence that the instrument measured a single construct (see Appendix 8), namely TSPCK (Malcolm, 2015). According to Park and Oliver (2008), identifying the components of PCK is a pervasive way to conceptualise the construct. The TSPCK model, as described in Chapter 2, comprises five knowledge components. Therefore, in order to provide an overview of the quality of teachers' TSPCK in stoichiometry, the overall performance is firstly described to provide a picture of the status of the teachers' TSPCK in the topic of stoichiometry. Secondly, the performance in one of these components is discussed to account for the distribution of the raw scores for the component. This component is discussed here as activities for the lesson planned in the Learning Study were developed as conceptual teaching strategies. Finally, the overall performance in the TSPCK Instrument is described in terms of how the components were integrated to measure a single construct.

4.3.1. Overall Performance in the Components of the TSPCK Instrument

According to Rollnick and Mavhunga (2014), the distribution of raw scores provides a qualitative picture of the status of the teachers' TSPCK in a topic. Figure 4.2 shows the percentage of teachers placed at the different ordinal scores 1 through 4 from the TSPCK rubric in each of the five categories A through E of the TSPCK Instrument. Category A, labelled as "A: LPK" is the component *learner prior knowledge*, Category B, labelled "B: CSA" is *curricular saliency*, the component *what is difficult to teach*, Category C in the instrument is labelled as "C: WDT" with Category D, *representations* labelled as "D: REP" and *conceptual teaching strategies*, Category E in the instrument labelled as "E: CTS". The scores, as mentioned when discussing the TSPCK rubric, are an indication of the different levels of TSPCK with '1' representing limited, '2' basic, '3' developing and '4' exemplary levels. These are the scores for the sample of 31 teachers used to determine the baseline quality of Gauteng teachers' TSPCK in stoichiometry.

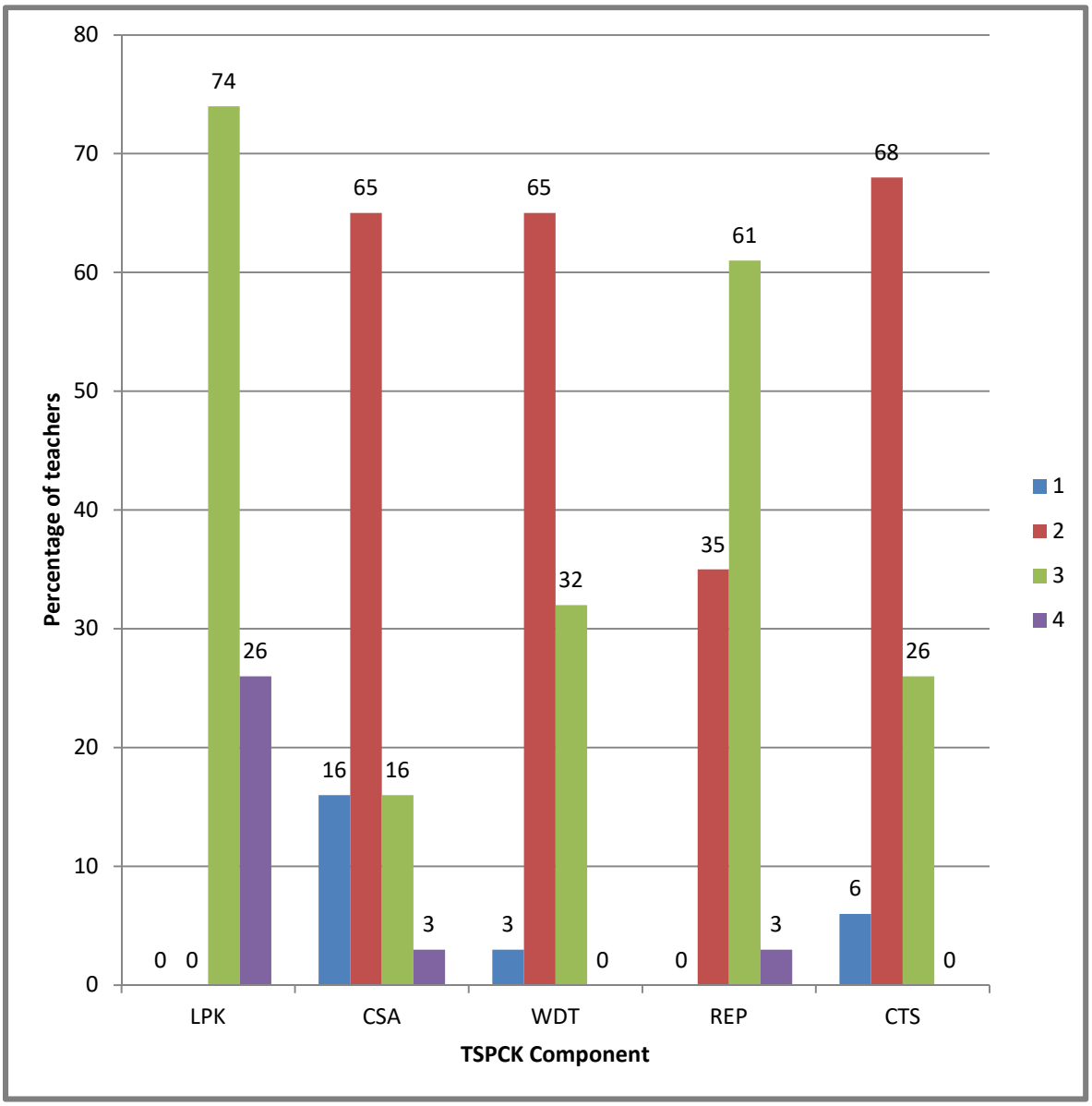


Figure 4.2: Teachers scores across the five components of TSPCK

As is evident in Figure 4.2, the teachers' scores in each component, with the exception of LPK where 74% of teachers centred around the developing level (3), are centred around the basic level (2) of TSPCK. With the exception of LPK the other four items yielded a spread of scores across the quality categories. For example, for the components CSA and WDT, more than 60% of teachers scored 2. The remaining teachers, although mostly centred around the developing (3) level, 16% and 32% scored '3' for CSA and WDT respectively. The expectation in terms of the interpretive argument for validity, was that the component CTS would prove the most challenging item in the instrument but this was not the case, since CSA was ranked the most difficult item (Malcolm, 2015). As can be seen in Figure 4.2, although 65% of teachers demonstrated a basic level of TSPCK for CSA and 68% for CTS, fewer

teachers demonstrated a developing level (3) of TSPCK for CSA than CTS. At a limited level (1), 16% of teachers scored '1' for the component CSA whereas only 6% of teachers scored '1' for the component CTS (refer to Appendix 8).

Examining the distribution of raw scores from Figure 4.2 described above aimed at providing an overview of the status of teachers' TSPCK in stoichiometry (Rollnick & Mavhunga, 2014). But it is the capacity of teachers to transform content knowledge through each of these five knowledge components that constitute TSPCK (Mavhunga & Rollnick, 2013). Therefore, in the subsections that follow, the qualitative analysis of the responses to the item that measured the knowledge component of CTS is discussed. For a discussion on the other items, refer to Appendices 12 and 13.

4.3.2. Performance in the Component Conceptual Teaching Strategies

The TSPCK component CTS, as discussed in the interpretive argument for validity (Kane, 2011), was expected to be the most difficult item in the instrument (Malcolm, 2015). Although the Rasch analysis indicated that the component of CSA was ranked as the most difficult because of the selection of big ideas (see Appendix 8), this item was still found to be challenging for teachers and ranked as the second most difficult item. The expectation that CTS is challenging for teachers is based on the fact that the use of conceptual teaching strategies requires the integration of the other four components of TSPCK (Rollnick & Mavhunga, 2014). Examples of how teachers' engaged with this item in terms of the quality of their responses are included in Appendix 8. In this subsection, an overview will be provided of how teachers analysed the student errors and the strategy they provided to deal with them (Rollnick & Mavhunga, 2014).

During the qualitative analysis of the instruments, each teacher's response was carefully analysed to see if they explicitly identified the learner errors in both responses (see student errors in Appendix 8). The way in which teachers responded to this item varied greatly, with some teachers first explaining what errors the students made in each extract before outlining a teaching strategy, whereas others in describing their teaching strategy mentioned what the errors were. In other cases, the learner errors were not mentioned explicitly, but the teacher's strategy emphasised the need to calculate the amount of substance to determine the limiting reagent. Such responses therefore acknowledge that the limiting reagent cannot be determined by looking at the mass of reactants, or the molar ratios of the reactants in the

balanced chemical equation and the learner errors are implicitly identified. Table 4.1 provides a summary of the types of responses provided by teachers.

Table 4.1: Summary of the ways in which teachers identified the learner errors

Identification of student error	Number of teachers	Example(s) of responses
Explicitly identifies both learner errors in response	11	"She is only using the balanced equation... the mass available without considering the mole ratio" "Learners cannot guess the answer by looking at the equation (i.e. molar ratios) or by looking at the mass" "The number of moles in the balanced chemical equation ... and mass of reactants don't immediately determine the limiting reagent"
Explicitly identifies one learner error in response	3	"Mass of a substance does not indicate the limiting reagent" "Mass is not the way to do it. You can't identify the limiting reagent by looking at the mass of the reactants but have to calculate the number of moles" "By explain that it is not the mass that is used but the number of moles when determining the limiting reagent"
Explicitly identifies learner errors broadly in terms of understanding concept	3	"The two extracts show that learners might not quite understand what limiting reagents mean" "Extract 1: error – definition of limiting reagent... extract 2: error – definition of limiting reagent" "Both students seem to have done not the calculations and don't then understand what the limiting reagent is"
Implicitly identifies errors in terms of students calculating amount of reactant/product to determine limiting reagent	12	"Learners need to be able to calculate the number of moles for each reactant" "The limiting reagent will have to be determined through calculation" "Always change mass, volume, concentration to number of moles"
Responses do not identify the learner errors explicitly or implicitly	2	"Learners must do corrections for the calculations" "To explain law of constant composition first then to compare and finally do the calculation"

More than half of the teachers explicitly referred to the learner errors to some extent in their responses. These varied from identifying both learner errors, with 11 of the teachers identifying that the students determined the limiting reagent from the molar ratios or the mass of reactants. Examples of how they identified the errors are included in the examples of the responses in Table 4.1. In some instances, the teachers either only identified one error, or explicitly stated that the student errors were related to them not having an understanding of the concept of limiting reagents. These responses indicate that the teachers are aware of the misconceptions and that students struggle with identifying limiting reagents (Huddle & Pillay, 1996; Potgieter *et al.*, 2005). The expectation in the component of CTS, as the integration of the other components (Rollnick & Mavhunga, 2014), was that teachers who exhibited exemplary PCK in LPK would have identified the learner error in this component. From the qualitative analysis of the responses, of the eight teachers who exhibited exemplary PCK in LPK (see Figure 4.2), only six explicitly identified the learner errors, at least broadly.

Over a third of the teachers, although not explicitly stating what the learner errors were, described a teaching strategy that implied that they were aware of the learner errors. The examples extracted from their responses in Table 4.1 indicate that the limiting reagent has to be determined by calculation. In such responses, the teacher is clearly presenting the information about how to determine the limiting reagent and clarifying the idea that the limiting reagent cannot be determined from the mass of the reactants. But as Posner, Strike, Hewson, and Gertzog (1982) point out, this is not adequate enough to help students accommodate new conceptions. In order for there to be conceptual change in students thinking, there must be dissatisfaction, and these strategies are not creating dissatisfaction with their existing concepts, since the teachers are not playing the role of an adversary in challenging the misconception (Hewson, 1981; Strike & Posner, 1982). Only two teachers provided responses that did not provide enough information to determine the extent to which they were aware of the student errors.

In addition to determining the extent to which teachers identified the learner errors in their responses during the qualitative analysis, the types of representations they used were also listed. Based on the rubric descriptors (see Appendix 2), teachers exhibiting developing TSPCK in this component were required to use at least two levels of representation. Therefore the types of representations used by the teachers were captured in the in-depth analysis of the responses (see Appendix 20). See Figure 4.3 for the analysis and grouping of the types of representations. Firstly, the representations are grouped according to the types of symbolic representations used, since the majority of teachers only referred to mathematical formula and/or the molar ratios in the balanced chemical equations. Included in symbolic representations is any type of written, step-by-step procedure to help students solve stoichiometric problems. The macroscopic representations include any analogies used by the teachers in explaining limiting reagents, and any demonstrations and/or practical activity related to limiting reagents. Sub-microscopic representations include any form of particulate diagrams, in conjunction with the balanced chemical equations or when explaining limiting reagents.

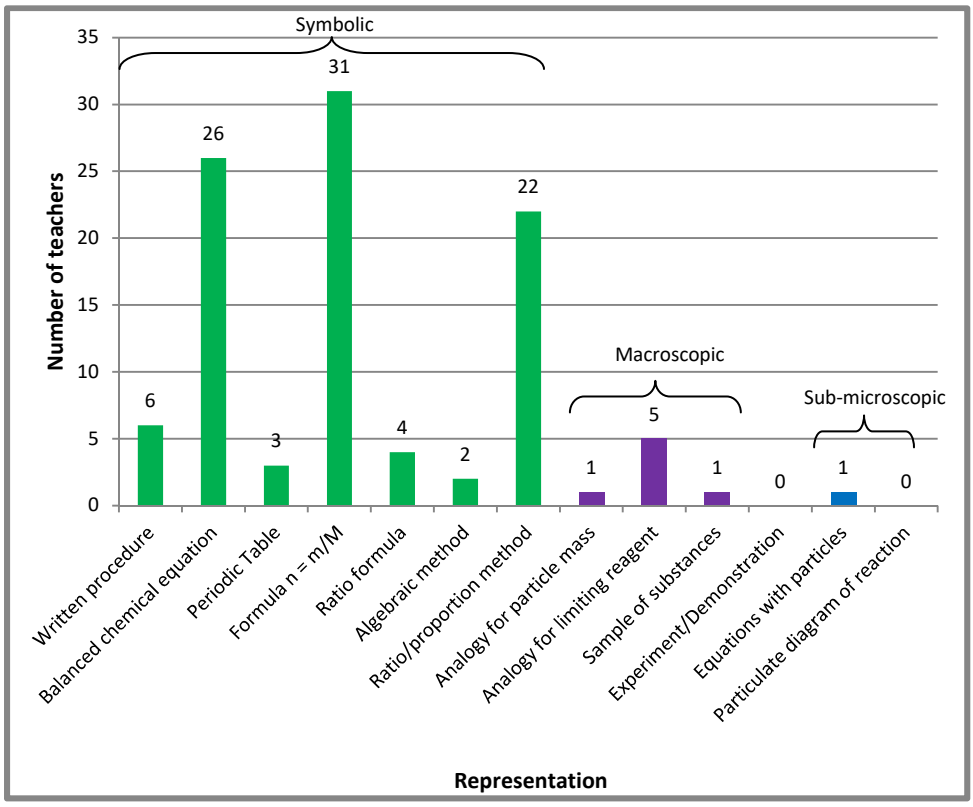
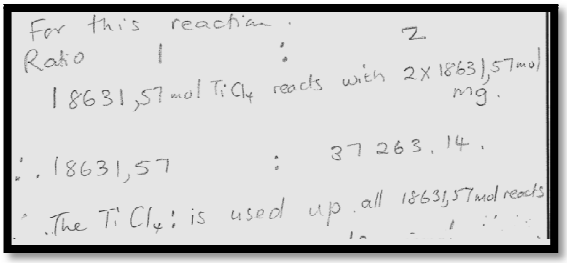


Figure 4.3: Bar graph of the different types of representation used by teachers in their conceptual teaching strategy

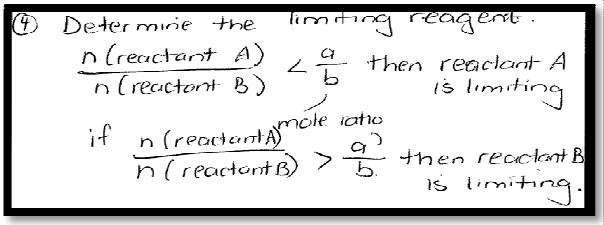
All of the teachers sampled used various types of symbolic representations as is evident in Figure 4.3. The most common representation used in the teaching strategies described was the formula for calculating the amount of substance, with all of the teachers stating that in order to determine the limiting reagent, students needed to calculate the amount from the mass of reactants. This is probably due to the teachers understanding that the mole as a unit of amount is an integral part of solving stoichiometric problems (Chandrasegaran *et al.*, 2009). Almost all the teachers who were sampled also included or made reference to the balanced chemical equation with twenty-six using this representation. The number of teachers who selected the symbolic representation of balanced chemical equations was slightly lower than the percentage of teachers who selected the symbolic representation of the mathematical formula for calculating amount, because those teachers who exhibited limited PCK did not provide detailed strategies in their responses. In these limited TSPCK responses for CTS, these teachers only mentioned the need to do calculations without incorporating the representation of the balanced chemical equation in their response.

The other symbolic representations used in the strategies described by the teachers are shown in Figure 4.4. Figure 4.4 includes extracts of the teachers' responses to show the different types of symbolic representations used to determine the limiting reagent.

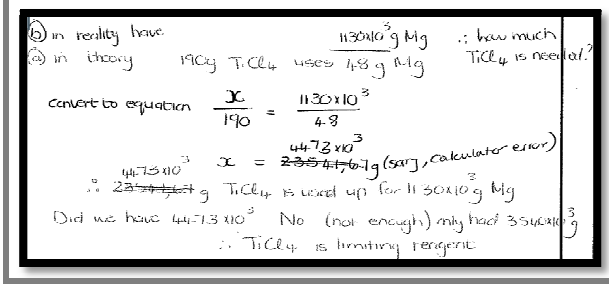
Example (i) of representation using ratios from first principles (conceptual)



Example (iii) of representation using algorithmic ratio formula (algorithmic)



Example (ii) of representation using algebraic method (algorithmic)



Example (iv) of representation using formula for amount to find the mass of product formed (algorithmic)

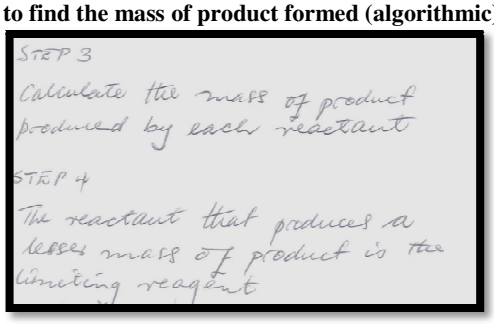


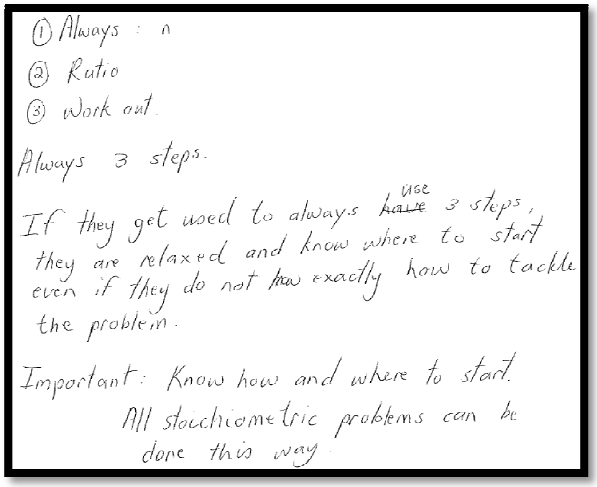
Figure 4.4: Examples of symbolic representations used to determine limiting reagents

Example (i) shows a typical response were teachers included the use of ratios or proportions in conjunction with the balanced chemical equation to determine the limiting reagent, with twenty-two teachers using this type of representation. This is linked to determining the limiting reagent from first principles by comparing the actual mole ratios of the reactants with the stoichiometric ratios of the balanced chemical equation (Chandrasegaran *et al.*, 2009). In some instances, teachers used the proportions to produce an equality expression, referred to as the 'algebraic method' shown as Example (ii) in Figure 4.4 or used an algorithmic ratio formula shown as Example (iii). The algebraic method was used by two of the teachers and the ratio formula was used by four of the teachers. Interestingly, three of the teachers, who included the formula for calculating amount shown as Example (iv) in Figure 4.4, used this representation to also calculate the mass of product and identify the limiting reagent based on the definition of limiting reagent. These teachers therefore did not include representations related to ratio or proportion by first principles, the algebraic method or the algorithmic ratio formula.

Two other visual symbolic representations were also included in some of the responses provided by the teachers. These included a step-by-step procedure for students to follow and reference to the periodic table. A visual procedure was included by 6 of the teachers and 3 of the teachers made reference to using the periodic table (See Figure 4.3). Examples of these responses are included in Figure 4.5. Macroscopic representations were used by 7 of the teachers as indicated in Figure 4.3. These macroscopic representations included using analogies to help students understand that the particles of substances have different masses, with one teacher using such analogies or everyday examples. Such analogies were also used by five teachers to help define limiting reagents. Examples, referring to the mass of reactants, were used by two of the teachers, and one teacher used actual samples to help students understand that mass cannot be used to determine the limiting reagent. However, none of the teachers included actual demonstrations to give students qualitative evidence of reacting ratios, such as the demonstration described by Wood and Breyfogle (2006). Practical work, which provides students with concrete examples of reactions, specifically if their attention is drawn to important observational stimuli in experiments, may be a prerequisite for developing conceptual understanding (Tsaparlis, 2009). Examples of these responses are also shown in Figure 4.5 on the next page, including the qualitative demonstration that could be used by teachers.

Very few teachers made use of sub-microscopic representations in their explanations or teaching strategies. As is evident in the bar graph in Figure 4.3, only one teacher used sub-microscopic particulate diagrams in explaining molar ratios in the balanced chemical equation. Although many teachers selected Representation 3 (see Appendix 13) and focused on the symbolic and sub-microscopic aspects of the representation they did not consider using a representation like this in their teaching strategy. Louise (P07), whose response to the item on conceptual teaching strategies shown in Figure 4.5 (example viii), only used the particulate diagrams to reinforce the idea of reacting molar ratios in a chemical reaction. In her response to the Category D item on REP, she also stated that she would use Representation 3 “only to explain balancing chemical equations”. None of the teachers used particulate diagrams, like the one in Figure 4.5, to help students understand limiting reagents. The particulate diagram shown in Figure 4.5, used in a question in the CK Instrument, is shown as a possible representation that teachers could have used to help explain limiting reagents.

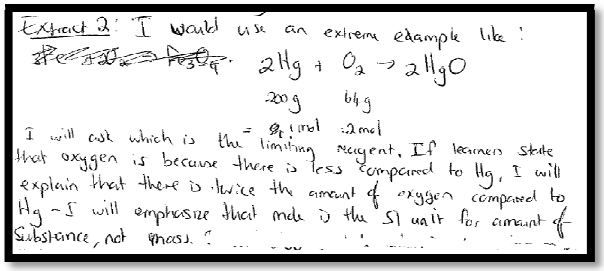
Example (i) of visual (symbolic) representation providing a procedure to follow



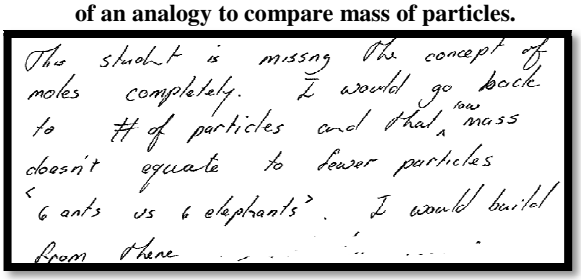
Example (ii) of visual (symbolic) representation making reference to periodic table

To drive home the fact that they can't just go on the mass of the reactants or the molar ratios I would stress the importance of using the periodic table to find the molar mass of each of the reacts. They have to calculate the number of moles from the mass of the reactants and so have to use the periodic table.

Example (iii) of macroscopic representation making use of example with mass of reactants



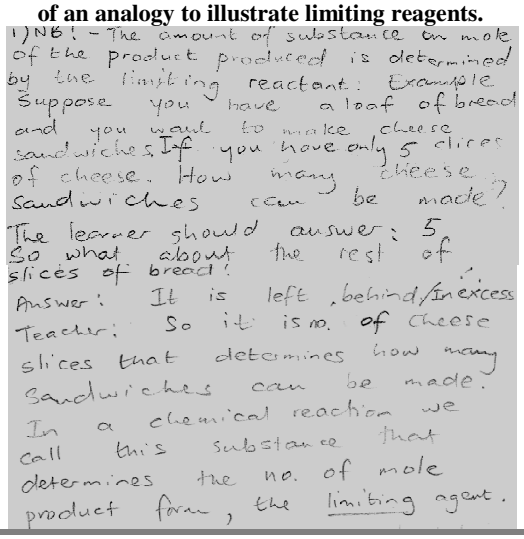
Example (iv) of macroscopic representation making use of an analogy to compare mass of particles.



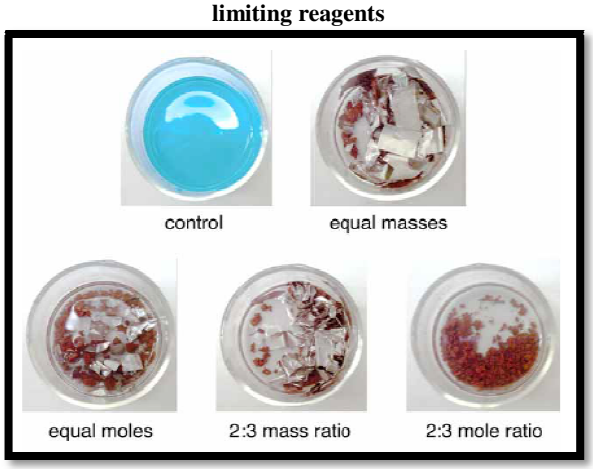
Example (v) of macroscopic representation making use of actual samples to compare mass of reactants.

The problem is that the kids think that the limiting reagent is the substance with the least mass. So I'd remind my kids that they have to convert the mass to moles so that they can compare number of moles with number of moles and of course the balanced equation and molar ratios. I keep these samples of 0.5 mol iron, sulphur and copper in my lab. The mass is written on each label so I'd show the kids that the same number of moles of these substances has different masses. So it is very important to convert the mass to number of moles.

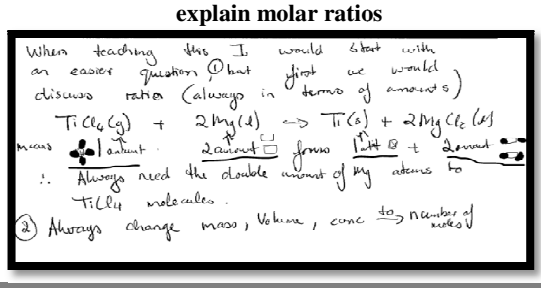
Example (vi) of macroscopic representation making use of an analogy to illustrate limiting reagents.



Example (vii) of macroscopic demonstration with aluminium and copper chloride that could be used to give students qualitative evidence of reacting ratios and limiting reagents



Example (viii) of sub-microscopic representation used to explain molar ratios



Example (ix) of sub-microscopic representation that could be used to explain limiting reagents

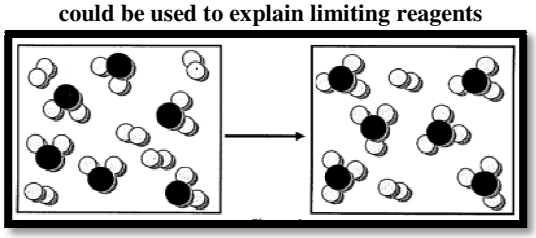


Figure 4.5: Examples of other representations used by teachers to explain limiting reagents

For students to develop conceptual understanding of concepts in chemistry, the use of sub-microscopic representations in conjunction with symbolic representations is considered important (Tsaparlis, 2009). However, the qualitative analysis of the TSPCK instruments revealed that all the teachers who completed the TSPCK Instrument used symbolic representations in their teaching strategy. This was expected since 'the symbolic language of chemistry is extensive, and is used ubiquitously in teaching and learning the subject' (Taber, 2009). However, the use of these representations as part of their teaching strategies also confirms the findings of a study conducted with Nigerian teachers, that most teachers use an algorithmic approach when teaching limiting reagents (Okanlawon, 2010).

A small number of teachers did use macroscopic analogies to explain limiting reagents and the key to using such analogies is that students understand them, and that they are familiar to students (Gabel & Sherwood, 1980). However, none of the teachers used macroscopic and submicroscopic representations together in their teaching strategy, but students should be able to understand the nature of the relationship between macroscopic representations and submicroscopic representations in chemical phenomena (Gilbert & Treagust, 2009). In using macroscopic and submicroscopic representations, teachers are helping students to build explanations by using models, and those that used analogies at a macroscopic level did so in order to help students build a picture of the reacting particles (Gilbert, Boulter, & Rutherford, 1998a). The use of particulate diagrams should be aimed at providing students with an understanding of the interpretative explanation of the reacting particles and why one substance is the limiting reagent (Gilbert, Boulter, & Rutherford, 1998b). Admittedly, this is difficult, as students often have problems in relating models, such as the mathematical modelling in stoichiometry, with other classes of models, such as macroscopic analogies or sub-microscopic particulate diagrams (Gilbert & Osborne, 1980). In order to help students relate macroscopic modelling with an interpretative explanation at a submicroscopic level, teachers have to ensure that they spell out, what Gilbert and Osborne (1980, p. 3) refer to as the 'conventions of interpretation'. Davidowitz and Chittleborough (2009) highlight that chemical diagrams at a submicroscopic level need to be used explicitly to help students make the necessary connections between macroscopic representations and submicroscopic representations. However, for students thinking at a macroscopic level and a submicroscopic level is considered difficult and abstract (van Berkel, Pilot, & Bulte, 2009) which might be

the reason none of the teachers used these representations together with symbolic representations and none of the teachers exhibited exemplary TSPCK in the component CTS.

A Limitation of Only Using an Instrument to Measure TSPCK

A limitation of only using the TSPCK instruments to measure PCK needs to be acknowledged here (Morrison & Luttenegger, 2015). During the baseline investigation, before constituting the PLC and to pilot the interview protocols, the teachers from the comparison group, Janet (C01), Christine (C02) and Hendrick (C03) were observed teaching stoichiometry lessons[13] to see TSPCK enacted in the classroom.

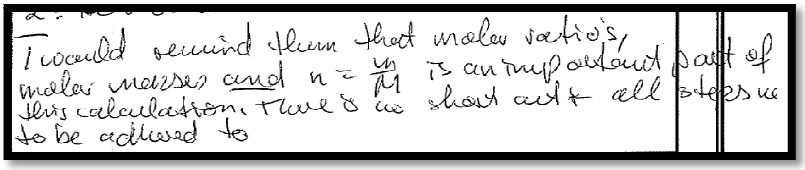
In Christine's lesson, she began by defining molar concentration and used the formula, a representation at the symbolic level to explain how concentration could be calculated. She then showed the students how to use the formula for molar concentration, with the variables for mass of the solute (m), molar mass of the solute (M) and volume of the solvent (V). She focused on these symbolic representations as an introduction, so that students could use the formula to make up a standard solution of known concentration. She summarised the steps that needed to be followed with a visual procedure, another symbolic representation written down on her interactive whiteboard as shown in Figure 4.6. The students then worked in groups and each group was given a different salt from which to make up a standard solution. The students then had to use the formula to calculate the mass of a solute needed, use a triple beam balance to measure out the calculated mass and dissolve the solute in water in a volumetric flask to make up the standard solution (see Figure 4.6). The laboratory work, the enactment of a macroscopic representation, gave students the opportunity to practice using the formula, a symbolic representation. Christine did not use any submicroscopic representations to explain why the concentration of the different salts was the same.

In their response to the Category E item on the TSPCK Instrument, both Janet and Christine only used symbolic representations, with Janet outlining that she would show students the calculations, and Christine emphasising that the formula to calculate amount is important in determining the limiting reagent (see Figure 4.6). Figure 4.6 also illustrates that, in practice,

[13] The lessons observed covered the concepts related to the mole concept, molar volume and molar concentration and not reaction stoichiometry and limiting reagents.

when teaching molar concentration, practical work, or representations at a macroscopic level, were used to explain the concept. The photographs in Figure 4.6 are from Christine's lesson.

Christine's response to item in Category E on CTS



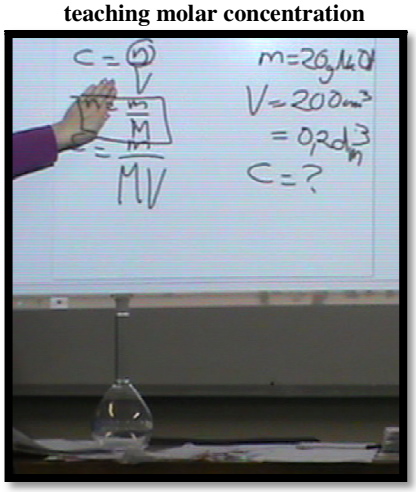
Janet's response to item in Category E on CTS

My strategy would first be to define the term limiting reagent, then explain that it is not from the mole ratio from the balanced equation alone nor the masses of the reactants that determines the limiting reagent but rather the number of moles of each reactant and the mole ratio from the balanced equation. I would also show them actual calculations.

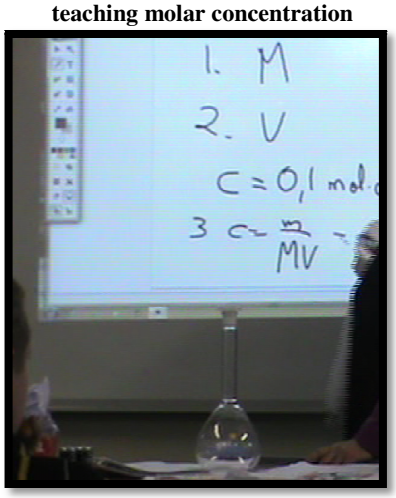
(1) The definition helps the learners to understand the concept of limiting reagent and calculations help to clarify any misconceptions.

(2) The definition is essential to the understanding of the concept. The calculations are important, as they give the learners visual and mathematical confirmation of the concept.

Symbolic representations used by Christine when teaching molar concentration



Symbolic representation used by Christine when teaching molar concentration



Practical Activity conducted in Christine's Class – finding the mass of solute

Practical Activity conducted in Christine's Class – dissolving the solute to make standard solution

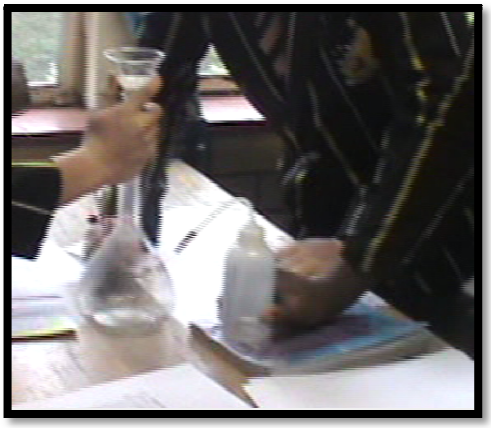


Figure 4.6: Christine's and Janet's Responses to Category E item and photographs of actual practice to illustrate the limitations of only using one method to measure PCK

When answering the TSPCK Instrument, Hendrick's response was very limited when describing how he would correct students' misconceptions related to limiting reagents (see

Figure 4.7). However, while observing his lesson on molar concentration, a more detailed picture emerged related to teaching strategies. Although he did not do any laboratory work, he began the lesson using a macroscopic example by asking students about the sweetness of sugar water if two, or three teaspoons of sugar were dissolved in water. From this example, he explained that the cup with three spoons of sugar was sweeter because it had a higher concentration. He then moved to symbolic representations and derived the formula for concentration from the units, providing examples that 32 grams of sulphur[14] dissolved in the same 'amount' (sic) of water as 5 grams of sulphur would be more concentrated (see Figure 4.7). He continued with symbolic representations and emphasised that from the mass, the moles can be determined. He then spent time showing students how different units of volume could be converted to decimetres cubed, using arrows and mathematical symbols as shown in Figure 4.7 due to student difficulties with converting units.

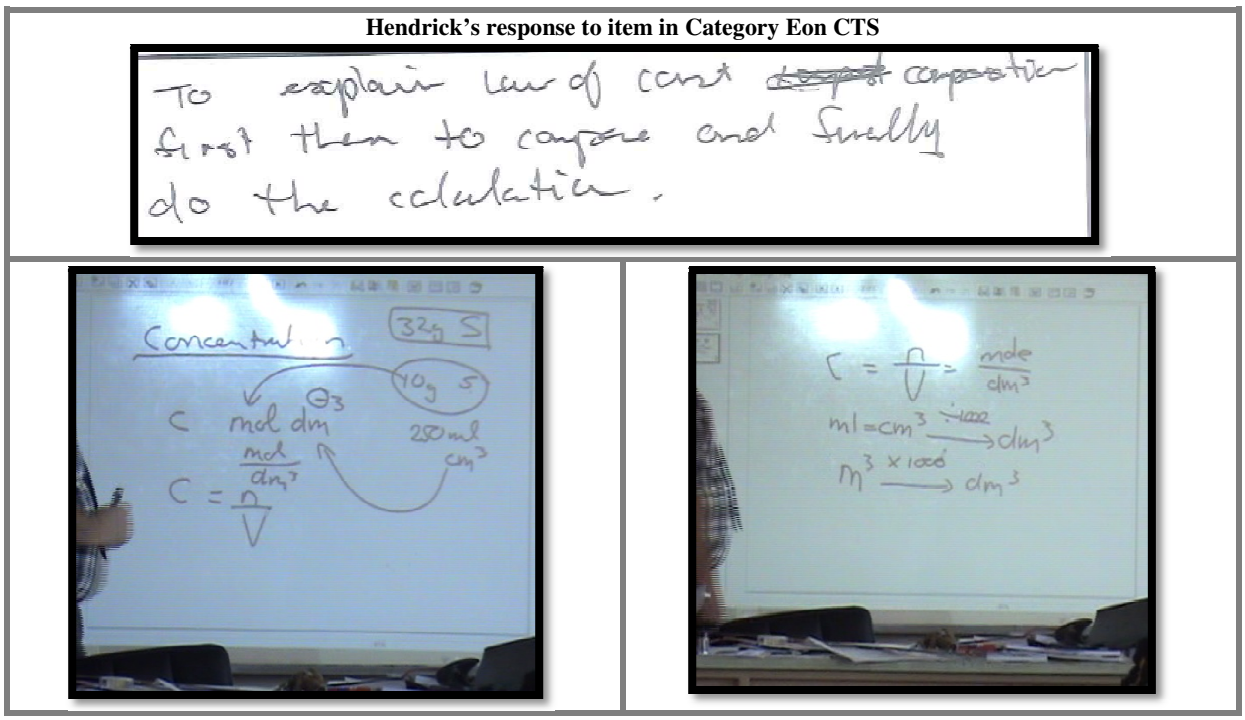


Figure 4.7: Hendrick's Response to Category E item and photographs of actual practice to illustrate the limitations of only using one method to measure PCK

The above examples from classroom observations highlight the limitations of simply measuring PCK through testing (Shulman, 1988). Despite the fact that the open-ended item was designed to yield a more elaborate response from the teachers, where the responses were brief, such as Hendrick's, this was interpreted as a lack of engagement (Morrison &

[14] Using sulphur as an example highlights that not all examples used by teachers are suitable as sulphur is insoluble in water. This is probably an indication of gaps in his content knowledge.

Luttenegger, 2015). However, the observations provided better insight into these three teachers' conceptual teaching strategies. In all three cases, despite the teachers only using symbolic representations in their responses, in practice they used macroscopic representations, whether in the examples given or in designing a lesson that included practical work. They however did not use submicroscopic representations.

This subsection has provided an overview of the quality of responses for the TSPCK component of CTS. The analysis focused on the extent to which the teachers engaged with identifying the student errors and the representations they used in their teaching strategy. The focus of most of the strategies was algorithmic, with teachers outlining that the amount of substance needed to be calculated from the mass of reactants and that the balanced chemical equation needed to be used to determine the limiting reagent. Various strategies, with the use of first principles using ratios to determine the limiting reagent being the most common, and the use of algebraic variables or an algorithmic ratio formula were described by teachers to show how they would assist learners in determining the limiting reagent. Based on this approach, just over two-thirds of the teachers were considered to exhibit basic TSPCK. Some of the teachers provided a procedure they would get their students to follow and only a small number of the teachers used some kind of macroscopic representation to help students understand their errors. The use of these macroscopic representations along with symbolic representations was an indication of developing TSPCK. However, none of the teachers used any form of practical work or demonstrations to qualitatively illustrate limiting reagents. In addition, none of the teachers used these macroscopic representations in conjunction with submicroscopic representations to explain the concept, Only one teacher used any form of submicroscopic representation and that was done in explaining reacting ratios in the balanced chemical equation for the reaction . The analysis in this subsection, and indeed this entire section thus far, has focused on the quality of the teachers' TPCK in individual components and the way in which they transform content knowledge in planning to teach (Mavhunga, 2012; S. M. Wilson, Shulman, & Richert, 1987). The next subsection examines the overall performance of the teachers in the TSPCK Instrument in terms of the integration of components.

4.3.3. Overall Performance in the TSPCK Instrument

Park and Chen (2012) state that although an in-depth and independent understanding of the components of PCK is useful to enhance knowledge about PCK, due to the integrative nature of PCK the interactions between components need to be investigated to provide insight into practice. In order to discuss the quality of teachers' TSPCK, it is therefore important to understand the interaction of the components (Abell, 2008). The Rasch analysis of the TSPCK Instrument provided statistical evidence with the fit indices that the instrument measured a single construct (Linacre, 2012). This can therefore be interpreted from a holistic perspective, in terms of the five components of TSPCK being integrated and enabling teachers to transform content knowledge into instructional events (Park & Chen, 2012).

The Fit Indices from the Rasch Analysis

Rasch analysis of item and person measure provide ZDST outfit and infit indices that indicate how well the data fit the Rasch model (Boone, Staver, & Yale, 2014). The infit indices indicate a positive expectation of responses to items by persons in terms of item difficulty and person ability, whereas the outfit indices indicate unexpected responses to items, quite distant from a person's ability level (Bond & Fox, 2001; Boone & Rogan, 2005). These fit indices are displayed graphically using *Winsteps Ministeps* (Linacre, 2012) to generate a bubble plot that indicates whether item difficulty measures and person ability measures fall within the acceptable range of +2 and –2 (refer to Figure 4.8). If these indices fall within this range, it is an indication that the items and persons work together to measure a single construct, thereby indicating construct validity.

The fit indices are indicated along the x-axis of the plot in Figure 4.8. The vertical axis of the plot indicates the hierarchy in ascending order of person ability and item difficulty on the same scale. The position of the bubbles indicates that the person has a 50% chance of correctly responding to an item of matching difficulty on the same scale. Persons with a lower ability measure are less likely to answer items higher up on the scale correctly and persons with a higher ability measure are less likely to answer items lower on the scale incorrectly. The size of the bubbles provides a visual representation of the error in estimating the respondent's position on the scale (Boone & Rogan, 2005). Where bubbles overlap, it is an indication of the degree to which the respondent's abilities are similar.

The fit indices on the horizontal axis of both items, which are indicated by the dark blue bubbles, and persons, indicated by the light blue bubbles, fall within the acceptable statistical range of +2 and –2. These fit statistics are an indication that the instrument measures a single construct. In the interpretive argument (see Malcolm, 2015), this single construct was identified as TSPCK, a theoretical construct that exists in a particular topic and that the five items, or components interact to develop TSPCK. These are therefore good fit indices and are evidence of the construct validity of the designed instrument to measure teachers' TSPCK in stoichiometry. In other words, a valid instrument for measuring teachers' TSPCK in stoichiometry was been designed based on the evidence provided by the fit statistics (see Appendix 8).

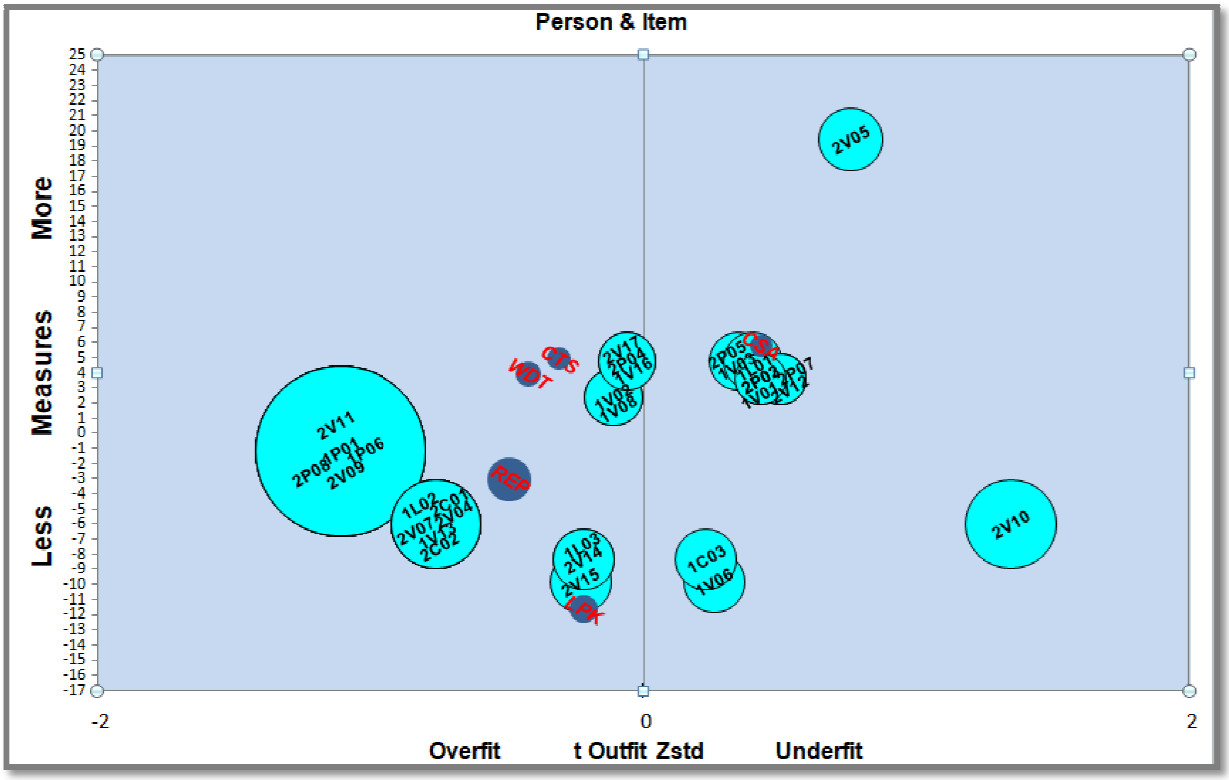


Figure 4.8: Bubble plot of fit indices for item difficulty and person ability for TSPCK generated through *Winsteps Ministeps* (N= 31)

Teachers' Overall Performance in the TSPCK Instrument Based on Rasch Analysis

The overall performance on the TSPCK Instrument is provided in Table 4.2 on the next page. The quality of the teachers' TSPCK is overall rated as basic TSPCK based on the raw scores. The raw mean score, however, only serves as an indication of the overall level of the teachers' TSPCK and do not take into account the difficulty gaps between the items, and hence the need to subject the raw scores to Rasch analysis. The teachers are ranked in order

of the Rasch measure, with Jeanine (V05) ranked the highest and Wilson (V06) and Nomsa (V15) ranked the lowest (refer to the person-item map in Appendix 8). The ordinal scores for each component of TSPCK are also included in order to compare these with the Rasch measure score.

Table 4.2: The ranked Rasch measure for each teacher determined through Rasch Analysis based on ordinal scores for each component of TSPCK

Person	Pseudonym*	Item Category Ordinal Scores entered in Rasch					Mean ordinal score	Rasch Measure (logits)
Code		A: LPK	B: CSA	C: WDT	D: REP	E: CTS		
V05	Jeanine	4	4	3	4	3	3.6	19.43
P04	Geraldine	4	2	3	3	3	3	4.79
P05	Mbali	3	3	3	3	3	3	4.79
V03	Beverley	4	3	3	3	2	3	4.79
V16	Jappie	4	2	3	3	3	3	4.79
V17	Mandy	4	2	3	3	3	3	4.79
P02	Suzette	3	3	3	3	2	2.8	3.59
P03	Palesa	3	3	3	3	2	2.8	3.59
P07	Louise	4	2	2	3	3	2.8	3.59
V01	Conrad	4	2	2	3	3	2.8	3.59
V12	Agnus	4	2	2	3	3	2.8	3.59
L01	Sipho	3	3	3	3	2	2.8	3.59
V02	Dumisani	3	2	3	3	2	2.6	2.38
V08	Peter	3	2	3	3	2	2.6	2.38
P01	Bongani	3	2	2	3	2	2.4	-1.18
P06	Tashin	3	2	2	3	2	2.4	-1.18
P08	Linda	3	2	2	3	2	2.4	-1.18
V09	Talia	3	2	2	3	2	2.4	-1.18
V11	Debbie	3	2	2	3	2	2.4	-1.18
V04	Natalie	3	2	2	2	2	2.2	-5.99
V07	Faith	3	2	2	2	2	2.2	-5.99
V10	Sindiswa	3	1	2	3	2	2.2	-5.99
C02	Christine	3	2	2	2	2	2.2	-5.99
V13	Denis	3	2	2	2	2	2.2	-5.99
C01	Janet	3	2	2	2	2	2.2	-5.99
L02	Tendani	3	2	2	2	2	2.2	-5.99
V14	Prudence	3	1	2	2	2	2	-8.33
C03	Hendrick	3	2	2	2	1	2	-8.33
L03	Sizwe	3	1	2	2	2	2	-8.33
V06	Wilson	3	1	1	2	2	1.8	-9.84
V15	Nomsa	3	1	2	2	1	1.8	-9.84
Mean score							2	2.5

* **Pseudonyms assigned to maintain ethical considerations.**

The Rasch measures indicated in Table 4.2 indicate that more than half the teachers scored below the group mean for the instrument (mean - 0.74, SE, 1.71). Although all of the teachers who scored below the group mean were able to identify good responses to common student misconceptions in *learner prior knowledge* (see column labelled A: LPK), all of their responses to the item *what is difficult to teach* (see column labelled C: WDT) were scored with an ordinal score of '2' except Wilson (V06). This is an indication that they identified specific concepts that were difficult to teach but gave generic reasons for the difficulties students had with these concepts (see Appendix 12).

The qualitative analysis of the responses indicated there was no integration of these difficulties with the two LPK questions and student misconceptions in stoichiometry. For example, Natalie (V04) whose overall logit score was -5.99 scored '3' for LPK and '2' for WDT. In her response to the Category A item, she identified the best response related to the misconception on molar volume, and, although she identified molar volume as a difficult concept to teach, her reason was linked to students not being taught the gas laws and not the misconception. In contrast, however, Geraldine (P04) and Conrad (C01) whose logit scores are 4.79 and 3.59 respectively, clearly linked the difficulties in teaching molar volume to the student misconception. Conrad, in his reasoning for selecting the response he did for the Category A item, stated "they might better understand the assumption being made with molar volume" and his reason for selecting molar volume as difficult to teach was "they don't know what assumptions are being made". Geraldine, in her reason for the Category A item stated that "it isn't uncommon to have students use 22.4 in concentration calculations" and in her reason for selecting concentration as a difficult concept to teach stated "students muddle up concentration with gas volume". These examples highlight that the teachers who scored above the group mean linked components whereas teachers who scored below the group mean did not integrate knowledge of LPK with WDT.

In terms of *curricular saliency* (see column labelled B: CSA), the teachers who scored below the group mean generally scored '2', indicating that they only identified one big idea. The five lowest scoring teachers, with the exception of Hendrick (C03), only identified subordinate ideas. I. Mitchell, Keast, Panizzon, and Mitchell (2017) state that one of the purposes of big ideas is to provide teachers with a way of restructuring students' existing ideas, or learner prior knowledge and can be directed at known problems of learning. Therefore, not being able to identify the gate-keeping concepts of the mole, concentration and

limiting reagents, these teachers are not integrating the components of LPK or WDT with the component of CSA. This integration is important, since identifying big ideas is crucial to helping teachers design activities, or conceptual teaching strategies that will elicit reflection and engage students in discussion and cognitive restructuring (I. Mitchell *et al.*, 2017). Based on the scores for *conceptual teaching strategies* (see column labelled E: CTS), most of the teachers who scored '2' for CSA scored either '2' or '1' for CTS. The component of CSA was the most difficult item of the instrument (Malcolm, 2015) and working with big ideas has been described as both difficult and foreign to teachers (I. Mitchell *et al.*, 2017). As is evident in Table 4.2, of the teachers who scored above the group mean, eight also only scored '2' in the component of CSA. But the qualitative analysis even of these teachers' responses did provide evidence of the integration of the components (see Appendix 12). Below are two examples to show how the logit scores provide evidence of the integration of components.

Louise (P07) for example only selected one of the framed big ideas for stoichiometry: that of the mole/Avogadro's number (sic). She stated that this was an important gate-keeping concept since students "need to know what we work with, the amount we can weigh and see". This idea was evident in her responses to the items in Category A, where she linked student difficulties to the idea of the mole as a number of particles, and that the same number of different particles has different masses. For the misconception related to molar volume, in her reasons for selecting the response she did, she stated "the teacher repeats what one mole is, i.e. a number 6.02×10^{23}" and that "for a solid and a liquid we have to look at masses as we cannot use their volumes". For the misconception related to equal masses and concentration, she stated "the learner has to know that $n \neq m$, but a number".

Louise's selection of the mole/Avogadro's number as a big idea was a means of working with a set number of particles, by finding mass was also integrated with the selection of representations in the Category D item. She selected a combination of representations, stating that she would introduce the mole concept using Representation 1 to "drive in the concept that a number of moles represents a certain amount [amount meaning number here] of particles". She stated that she uses the formula triangle, or Representation 2, to mathematically prove from the molar mass of a substance, which is a ratio of the mass per number of particles ($M = m/n$) that the 'number of moles' $n = m/M$. This integration continues into her teaching strategy where she provides a procedure that highlights that the "amounts that we can weigh and see", such as mass, volume and concentration need to be

converted to ‘number of moles’ [meaning the number of particles] in order to determine the limiting reagent, where she used Representation 3, to show the number of particles that react in the given balanced equation. Although she only selected one big idea, this big idea is integrated into her understanding of LPK, the way she uses REP and how these come together in her CTS. Therefore, her logit score that is above the group mean average, provides an indication of her integration of TSPCK components.

Christine (C02), on the other hand, whose logit score is below the group mean at -5.99 logits also selected the mole as a big idea. She stated that it was “a very important and indispensible concept to cope with stoichiometry” but did not show any integration of the components beyond the consistent use of the mathematical formula. Her reasons for selecting the responses she did for LPK did not focus on the actual misconceptions related to the mole but on students’ study skills and what they should already be familiar with. She selected Representation 2, the formula triangle and provided a step-by-step procedure for how students should use it without linking it to the big idea of the mole. Her conceptual teaching strategy was a three-step procedure for students to follow, including using n = m/M as an important step. In her explanation, there is no emphasis on the importance of the mole concept in solving the problem but rather that students need to practice in order to be successful in stoichiometric calculations. Her low logit score is therefore an indication of her lack of integration of components.

Another component that highlights the lack of integration is that of *representations* (column labelled as D: REP). Although many teachers selected the representation with all three levels of representation (see Appendix 13), the interaction of this component with conceptual teaching strategies was lacking since 12 of the 19 teachers who scored ‘3’ for Category D: REP only scored ‘2’ for Category E: CTS (see Table 4.2). As has been discussed in the subsection on performance in conceptual teaching strategies, the teachers only used symbolic representations in their teaching strategy. The teachers who scored ‘3’ for conceptual teaching strategies used macroscopic representations along with symbolic representations. The distribution of scores for conceptual teaching strategies, which requires the integration of the other TSPCK components (Rollnick & Mavhunga, 2014), for the teachers who scored above the group mean highlight that 8 of the 14 teachers showed higher levels of integration of the other components. This integration is evident in that they explicitly identified the learner errors and used different levels of representation in their teaching strategy. This is

consistent with the findings described by Park and Chen (2012), who found that teachers' knowledge of learner prior knowledge may not necessarily be connected to their knowledge of instructional strategies or representations. The low logit scores, therefore, are an indication of the lack of integration between TSPCK components. Of course, the study conducted by Park and Chen (2012) focused on studying the integration of components by mapping these out and observing teaching practice, whereas the above descriptions focused on scores for the different components in comparison to teachers' overall logit scores. What is evident is that, at least in the reasoning and responses to the items, teachers with a higher logit score consistently integrate the components to some extent.

This section has provided an overview of the quality of the teachers' TSPCK in terms of overall performance, and of performance in one of the components of TSPCK, namely conceptual teaching strategies. The other components are discussed in Appendices 12 and 13. An attempt has been made to highlight the possible integration of the components based on the overall Rasch measure. Generally teachers with high logit scores from the qualitative analysis integrated TSPCK components whereas those with low logit scores did not integrate components. Generally, the higher the logit score, the more teachers have shown integration between the components of TSPCK. The limitations of only using the TSPCK Instrument to measure the quality of the teachers' TSPCK has also been highlighted by including examples from the lesson observations of Hendrick, Christine and Janet during the baseline assessment of TSPCK enactment in the classroom and piloting of the interview protocols. These observations showed that the TSPCK scores in the instruments may not always provide the best reflection of a teacher's TSPCK, and that using instruments alone to measure PCK has limitations (Morrison & Luttenegger, 2015). Since teachers require knowledge of the content they are required to transform (S. M. Wilson *et al.*, 1987), in the next section, the results from the analysis of the CK Instrument are presented to provide an overview of the quality of the teachers' content knowledge.

4.4. Performance in the Content Knowledge Instrument

Content knowledge is an important precursor for developing PCK (Kind, 2009a; Rollnick *et al.*, 2008). The items used to determine the respondents' CK were selected and adapted from various sources (refer to Appendix 10) and consisted of multiple choice items and open-ended items. The thirty-one teachers who completed the TSPCK instrument also completed

the CK instrument. The scoring is briefly outlined in this section. The validity and reliability of the CK Instrument was briefly discussed in Chapter 3 and this section aims to provide an overview of the quality of the teachers' content knowledge using the valid instrument. The capturing of the teachers' content knowledge was undertaken because of the underlying assumption that content knowledge and PCK are interrelated (Even, 1993; S. M. Wilson *et al.*, 1987).

Scoring the CK Instruments

The data from the CK instrument was analysed both quantitatively and qualitatively. A marking memorandum of correct answers (included in Appendix 3) was used to score the instrument on a continuous level. The responses were scored either as a '1', for a correct response and '0' for an incorrect response to obtain a total score. Based on the response provided for Question 2, in which respondents were asked to define the mole in their own words, the response was coded either as F1, F2, F3 or F4, based on the conception of the mole described in Chapter 2 (Strömdahl *et al.*, 1994) as shown in Figure 4.9.

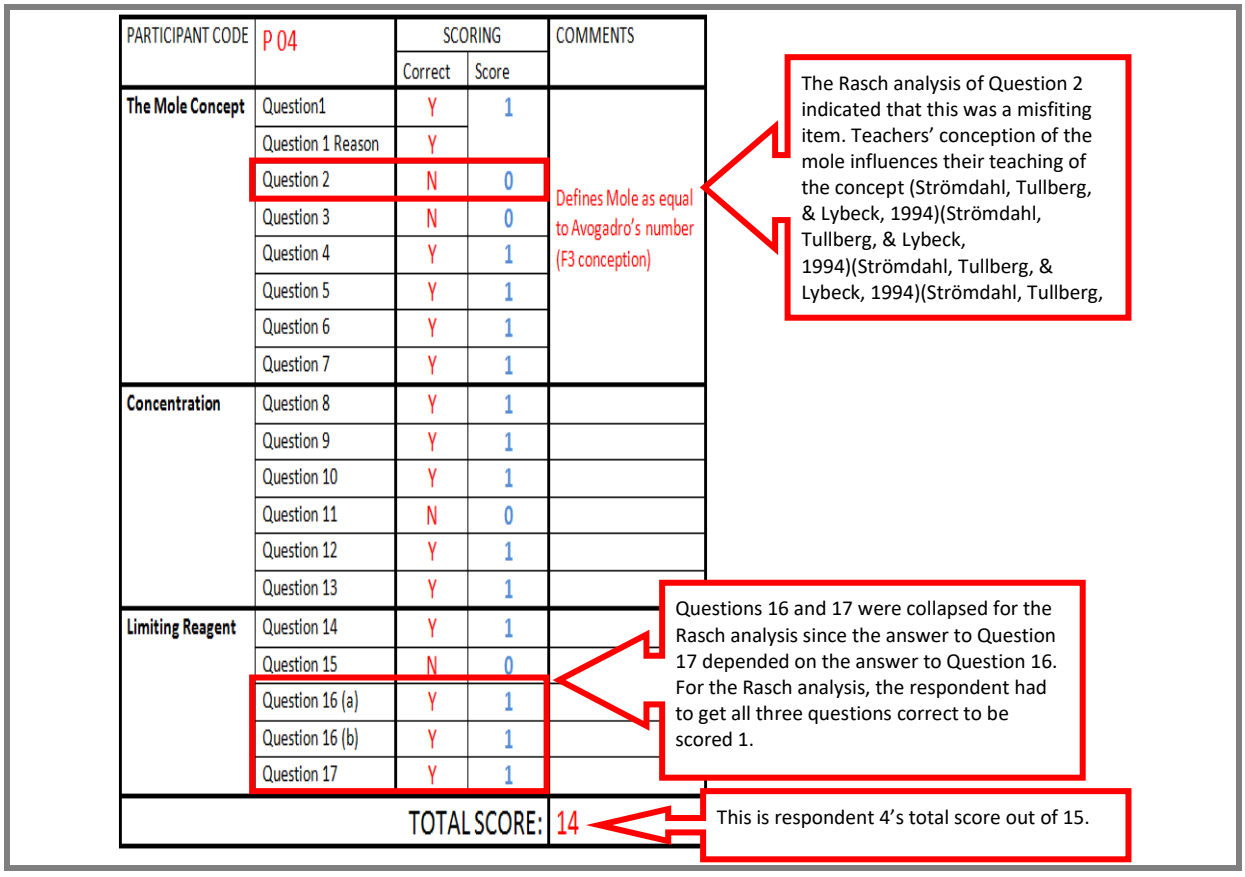


Figure 4.9: Sample of a score sheet used to determine the total score for the Content Knowledge instrument

The responses from the marked instruments were captured and recorded on a score sheet, as shown in Figure 4.9, which is a sample of the score obtained for one participant. If the response was correct, a 'Y' was recorded and scored a '1'. Incorrect answers were indicated using 'N' and scored a '0'. In this case, the respondent defined the mole as a 'number' and this was indicated with the code 'F3'. The total score was obtained by adding up all the correct responses. The dichotomous scoring, conception of the mole and total score captured from the scoring sheet for each respondent is included in Appendix 18. The results of this analysis are provided in Appendix 11.

Teachers' Overall Performance in the CK Instrument Based on Rasch Analysis

The Rasch analysis of both the dichotomous data and the multiple-choice questions generated item response tables that provided a number of correct and incorrect responses, and, for multiple-choice questions, a number of respondents who selected the different distracters. The teachers' overall level of stoichiometric CK will be discussed in this section. For an analysis of the responses of the most common errors made by teachers when completing the CK Instrument that merit discussion, refer to Appendix 14.

The raw scores for the CK Instrument, a total out of 15[15], were converted to a percentage similar to the study conducted by Ndlovu (2014), when assessing Grade 12 Physical Sciences teachers' content knowledge in electrochemistry. The critical acceptable score to represent good CK was taken to be 60%. The raw scores, percentage and the Rasch measure are included in Table 4.3. The scores are shown in ranked order from highest logit score to the lowest logit score.

The mean score of this sample of experienced physical science teachers was 72%, or 1.63 logits for the Rasch measure indicating that the majority of teachers demonstrated good levels of mastery of stoichiometric CK (see Table 4.3). Generally, the majority of teachers scored above 60%, with 7 teachers demonstrating levels of achievement below 60%. Approximately half of the teachers scored 70% or above and three teachers scored between 50 to 59%, just below the critical acceptable rating. As is evident in Table 4.3, there were four teachers who scored more than 10% below this critical acceptable rating, with Mbali (P05), Dumisani

[15] Based on the Rasch analysis Question 2 was a misfiting item and was not included in the score for teachers' CK in Stoichiometry.

(V02) and Prudence (V14) scoring 37.5% and Nomsa scoring 25%. Generally, teachers with lower scores tended to get the more conceptual type questions wrong in the CK Instrument. For a more detailed description of teachers' performance in the CK Instrument, refer to Appendix 14.

Table 4.3: Quantification and Ranking of Grade 11 Physical Sciences teachers achievement in the CK Instrument for stoichiometry (N = 31)

*Respondents		Raw Score	Rasch score (logits)	Percentage
CODE	****Pseudonym**			
P01	Bongani	15	4.6	100
P07	Louise	15	4.6	100
V05	Jeanine	15	4.6	100
V16	Jappie	15	4.6	100
V17	Mandy	15	4.6	100
V01	Conrad	14	3.29	93
V12	Agnus	14	3.29	93
C01	Janet	14	3.29	93
P02	Suzette	13	2.93	87
L01	Sipho	12	1.8	80
P04	Geraldine	12	1.8	80
V11	Debbie	12	1.8	80
C02	Christine	12	1.8	80
V08	Peter	12	1.32	73
L02	Tendani	12	1.32	73
V03	Beverley	11	1.32	73
C03	Hendrick	11	1.32	73
P08	Linda	10	0.92	67
V06	Wilson	10	0.92	67
V09	Talia	10	0.92	67
V13	Denis	10	0.92	67
L03	Sizwe	10	0.92	67
P03	Palesa	9	0.55	60
V04	Natalie	9	0.55	60
P06	Tashin	8	0.19	53
V07	Faith	8	0.19	53
V10	Sindiswa	8	0.19	53
V14	Prudence	6	-0.52	40
P05	Mbali	5	-0.89	33
V02	Dumisani	5	-0.89	33
V15	Nomsa	4	-1.31	27
Mean scores		10.8	1.63	72

*Pseudonyms assigned to maintain ethical considerations.

However, three important observations were made that indicate some teachers have similar problems to learners in stoichiometry. Firstly, some teachers could solve the algorithmic problems but struggled with the conceptual problems. Studies have found that learners can be taught to solve stoichiometric problems algorithmically but are unable to solve problems that assess conceptual understanding (BouJaoude & Barakat, 2003; Tóth & Sebestyén, 2009). Secondly, some teachers made errors in problems that could have been avoided if they had considered using submicroscopic representations as aids. It has been noted that learners fail to grasp chemical concepts if they fail to link chemical changes at a macroscopic level to a mental model of the entities involved at a submicroscopic level (Bond-Robinson, 2005). Thirdly, a small number of teachers seemed not to understand what was meant by the word amount. The term 'amount' has a very specific meaning in stoichiometry, but many teachers do not use this term and, as a result, learners are unable to solve stoichiometric problems (Packer, 1988).

The discussion of the teachers' CK scores outlined from here on, uses the Rasch measure rather than the raw scores. This has been done since there was no missing data, in that all the teachers answered all of the questions, therefore there is one logit measure that corresponds to each possible raw score (Linacre, 1998). Since the fit indices obtained through the Rasch analysis indicated that the items work together to measure stoichiometric content (refer to Appendix 11), the raw scores do convey meaning to the quantity being measured (Salzberger, 2010) and are therefore useful in equating scores (J. Stewart, 2012). In addition, the raw score-to-measure correlation (see Appendix 21) from the Rasch analysis was 0.98 indicating that the relationship between raw scores and Rasch measures is effectively linear (Linacre, 2002), and therefore comparisons can be made using logits rather than raw scores since the intervals between raw scores can vary greatly (J. Stewart, 2012). Therefore, due to this correlation, teachers such as Palesa (P03) and Natalie (V04) who scored 9 in terms of the raw scores represent the acceptable critical percentage of 60% which on the Rasch scale is 0.55 logits. As is evident in Table 4.3, of the sample of thirty-one teachers, only four teachers scored negatively on the logit scale. In addition, three teachers scored below the acceptable critical score. These 7 teachers, therefore, lack the necessary content knowledge in stoichiometry as measured by the CK Instrument. The mean score, in logits is 1.63 logits and just under half of the teachers achieved a score higher than the mean score. Therefore, most of the teachers sampled have a fairly good grasp of stoichiometric content knowledge. The

final question that needs to be answered when describing the quality of teachers' TSPCK in stoichiometry is to determine if there is a relationship between the respondents' TSPCK and CK. This is discussed in the section that follows.

4.4. Relationship between TSPCK Scores and CK Scores

In the previous section, it was reported that generally the teachers demonstrated considerably good CK, with a mean score of 1.63 logits for the Rasch measure. The Rasch measures (Table 4.2 and Table 4.3) were used to determine if there is a relationship between respondents' CK and TSPCK. The reason for using the Rasch measures rather than the raw scores is based on the argument that the Rasch scale is a statistically proven scale that compares each item score to an expected score based on the overall scaling model (Prieto, Alonso, & Lamarca, 2003). By conducting Rasch analysis on the scores of both the TSPCK Instrument and the CK Instrument, linear measures from the counts of qualitatively-ordered observations have been constructed (Salzberger, 2010), and, according to Prieto *et al.* (2003), it is preferable to use these measures in statistical analysis. This section aims to determine the relationship, through correlation statistics of the measured TSPCK and CK for the teachers who completed both instruments.

Correlation statistics are used to measure the degree of association between two sets of scores (Creswell, 2012). The correlation between TSPCK in stoichiometry and stoichiometric CK was determined using *Pearson's product-moment correlation* of the Rasch measures. This correlation statistic expresses the relationship between the two scores as a linear relationship (Creswell, 2012). The correlation coefficient, or *r*, is expressed as a numerical value between –1 and +1, with a positive number expressing a positive relationship, and a negative value expressing a negative relationship (Arcidiacono, 2014). According to Creswell (2012), the association between two scores reflects whether there is a consistent, predictable association between two sets of scores. The correlation coefficient was therefore determined from the Rasch measures for the thirty-one teachers that completed both the TSPCK Instrument and the CK Instrument. The correlation coefficient, *r,* calculated using the *Statistical Calculator* (Arcidiacono, 2014) was calculated as 0.51 ($p < 0.01$). This value indicates that there is only a moderate positive relationship between Grade 11 teachers' TSPCK in stoichiometry and their stoichiometric CK (Mukaka, 2012). A linear regression analysis of the TSPCK scores and CK scores by the *Statistical Calculator* (Arcidiacono, 2014) indicates this moderate

positive relationship between the two variables is a linear relationship through a straight line equation, with the line of best fit that most closely models the relationship (refer to Figure 4.10). The correlation analysis and linear regression analysis is included in Appendix 21. The value of the correlation coefficient, in this case, has some predictive value, according to Creswell (2012) and is therefore useful in exploring the relationship between the participants' TSPCK scores and CK scores. Creswell (2012) also emphasises the need to determine how meaningful the correlation between the variables is through significance testing. This was done using the *Wilcoxon Paired Signed Rank test* (Stangroom, 2017). The test is suitable for use in the analysis of the data in this study, since two different treatments were conducted on the same sample and the sample is relatively small. Analysis is, therefore, best served by non-parametric techniques (Conover, 1980).

For a correlation analysis, the null hypothesis is that there is no relationship between the two variables (Creswell, 2012). The Rasch measures for both the TSPCK Instrument and the CK Instrument were subjected to the *Wilcoxon signed rank test*. Since the sample size is 31, with a W-value of 137 the distribution is approximately normal and the Z-value can be used to evaluate the null hypothesis. The Z-value is –2.17 with a p value of 0.03, which indicates that the result is significant at $p \leq 0.05$ and the null hypothesis can be rejected. There is, therefore, a relationship between the respondents' content knowledge and topic-specific PCK in stoichiometry. Since CK is considered a precursor to TSPCK this relationship is expected (Rollnick & Mavhunga, 2014). Ndlovu (2014), when reporting on the correlation between Grade 12 teachers' TSPCK and CK in electrochemistry, also indicated that there was a moderate positive relationship between the respondents' TSPCK and CK.

The placement of teachers into categories based on their CK and TSPCK scores is worth noting since a moderate positive correlation was obtained. The placement of respondents into four quadrants, based on their CK scores and TSPCK scores, is shown in the scatter plot in Figure 4.10, along with the linear relationship determined from the linear regression analysis. There are some important aspects to note in terms of the scaling and descriptions in Figure 4.10. These are:

- The origin of the x-axis is set at the Rasch measure of approximately 0.55 for CK, since this represents a raw score of 60% (Teachers P03 and V04 scored 60% as shown in Table 4.3) and this was considered the critical minimum value for CK.

- The origin of the y-axis is set at the Rasch measure of 0 since this was the mean score for the items from the Rasch analysis.
- The regions above these values are considered as high CK and high TSPCK whereas the regions below these values are considered as low CK and low TSPCK (Rollnick & Mavhunga, 2014).

According to Rollnick and Mavhunga (2014), the expectation is that there should be no teachers with a low CK score and a high TSPCK score since CK is considered a precursor for the development of PCK (Rollnick *et al.*, 2008). But, as can be seen in Figure 4.10, there are two teachers placed within this quadrant, namely Mbali (P05) and Dumisani (V02). These two respondents typically failed to answer conceptual questions correctly in the CK Instrument, the reason for their low CK scores. There was a need to return to the raw data and their responses to the TSPCK Instrument. A brief discussion is warranted of Dumisani's and Mbali's placement in Figure 4.10 based on their responses to the items.

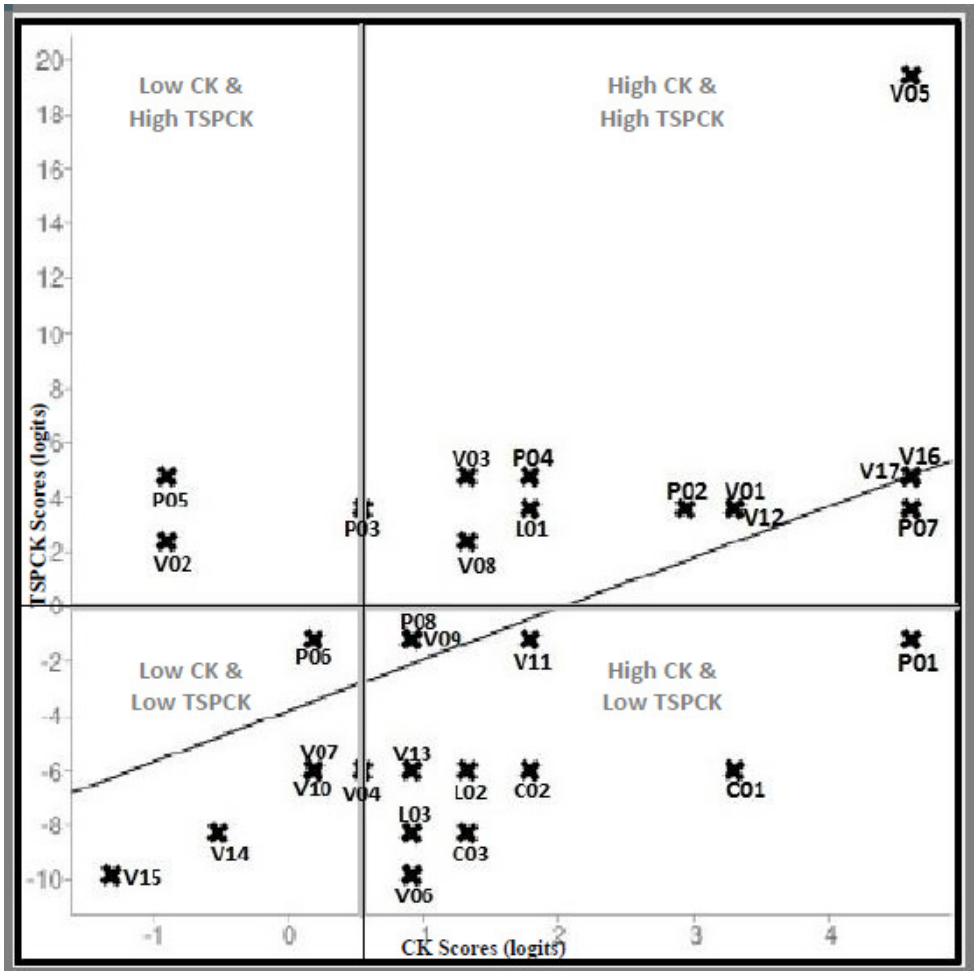


Figure 4.10: Relationship between CK and TSPCK of teachers in stoichiometry

Dumisani's mean TSPCK score was elevated by his response to the REP item. He selected a representation that included all three levels of representation and he provided extensive explanatory notes on how he would link the different levels of representations when using the representation in explaining how to balance chemical equations. In consultation with a member of the reference team, she agreed that his ordinal score of 3, representing developing TSPCK, was justified. She agreed that his score should not be higher since his explanation of how he would use the representation was not specifically linked to stoichiometric content. In the LPK category, he selected responses that were scored as showing developing TSPCK. However, his reasons lacked substance in that, for the first question, he only provided the standard definition and, with the second question, he did expand on the standard definition. However, when scoring the rule that a question with a response falling across two categories was scored based on the highest level of TSPCK illustrated was applied (Mavhunga, 2012). Dumisani was able to recognise good responses to learner questions and selected these responses but based on his reasoning; if presented with an open-ended response, he may not have been able to format his own response in a way that represented developing TSPCK. Dumisani also has almost twenty years teaching experience, and his experience may have allowed him to develop adequate expertise to teach stoichiometry algorithmically and use representations effectively.

Mbali (P05) from an analysis of the incorrect responses to the CK Instrument struggled with the conceptual questions too. There is no doubt from the literature, that learners, and as seen from the scores in the CK Instrument, even teachers, can solve stoichiometric problems algorithmically and yet fail to develop a conceptual understanding (BouJaoude & Barakat, 2003; Schmidt & Jignéus, 2003). Mbali, when questioned about the CK Instrument, admitted that she focused on teaching learners how to do the calculations and struggled with conceptual questions. She also admitted to completing the instruments late at night, and could have consistently made errors to such an extent that her responses were not flagged as idiosyncratic. However, Mbali also has experience in working in the field of instrument design to measure TSPCK, having completed a Master's research project in the design of an instrument for a chemistry topic[16]. Mbali's familiarity with the components of TSPCK and the scoring process may have possibly been advantageous in her reasoning through the

[16] In order to maintain anonymity the chemistry topics for which Mbali and Palesa developed TSPCK instruments has not been identified.

TSPCK components, as was evident in her responses to items in the TSPCK Instrument. This, therefore, could explain her placement in the High TSPCK, Low CK quadrant in Figure 4.10. Palesa (P03) is on the critical minimum score for CK but is placed in the high TSPCK quadrant also. She also admitted to struggling with teaching stoichiometry and stated: "I am anxious when I teach stoichiometry because of the questions learners could ask". She was also busy with a Master's degree in designing an instrument to assess teachers' TSPCK in a chemistry topic. The placement of Mbali and Palesa in the quadrant of High TSPCK, Low CK could be evidence of the transfer of their pedagogical transformation competence, in that the skills developed in transforming CK in the topics they developed instruments for, was seen in the quality of their responses for the TSPCK Instrument in stoichiometry (Mavhunga, 2016).

The majority of teachers fall into the right hand quadrants of reasonable to high CK, but, as Rollnick and Mavhunga (2014) state, it is possible for teachers with reasonable CK to lack the necessary knowledge to transform content knowledge into a teachable form. Of the twenty-four teachers with reasonable CK, twelve fall into the quadrant with low TSPCK. This includes Bongani (P01), who had one of the highest CK scores. However, he did not have a high TSPCK score as he only identified one big idea and used an algorithmic approach in his conceptual teaching strategy. Therefore, although CK is a precursor for PCK it is evident in this example that having good CK does not necessarily imply that a teacher has the good PCK. The qualitative analysis of their responses to the five components generally indicated that they used only one or two levels of representation, only identified one big idea and provided generic reasons mostly related to students' mathematical ability for student difficulties. In terms of their teaching strategies, the focus was on an algorithmic approach to deal with student difficulties. There is also the possibility of teachers falling into the quadrant with low scores for both constructs and five teachers are within this quadrant. As can be seen, twelve teachers fall into the quadrant with high CK and High TSPCK, although Jeanine (V05) has outperformed all of the other teachers, due to her experience in the field of designing an instrument to measure TSPCK in a very difficult chemistry topic[17].

[17] In order to maintain anonymity the chemistry topic for which Jeannine developed a TSPCK instrument has not been identified.

This section has described that a moderately positive relationship, that is statistically significant, exists between the teachers' CK and TSPCK. Although the expectation is that no teachers should fall into the quadrant of low CK and high TSPCK, one of the teachers who did, and one who was on the border of low CK highlight the possible transferability of the competence in working with the construct of TSPCK in designing instruments in other topics. A number of teachers, with reasonable CK exhibited low levels of TSPCK due to their inability to transform their content knowledge in teachable forms to develop conceptual understanding of stoichiometric concepts but focused on an algorithmic approach to teaching (Gess-Newsome, 1999a, 1999b). These two factors therefore contributed to the moderate positive correlation between CK and TSPCK. In the section that follows, the teachers' conception of the mole, which according to Tullberg *et al.* (1994) plays an important role in the teaching strategies used when teaching stoichiometry, is discussed.

4.5 Teachers' Conceptions of the Mole

The issue of the teachers' conception of the mole has been described as central to the root cause of student difficulties in stoichiometry (Strömdahl, 1996). Therefore, it was considered essential to determine the teachers' conception of the mole. In this section, evidence for the various conceptions held by the respondents is provided. A more detailed account is provided in Appendix 14.

A few examples of teachers' responses to Question 2 are shown in Figure 4.11. The responses shown in Figure 4.11 illustrate the different conceptions of the mole as described by Strömdahl *et al.* (1994).

(1) Firstly, Dumisani's answer clearly defines the mole as the amount of substance that is equivalent to the number of particles in twelve grams of carbon, a definition consistent with the SI definition, and coded as F4[18] (see Figure 4.11).

(2) Beverly's response, on the other hand, clearly equates the mole as equal to Avogadro's number of particles, or equal to 6.02×10^{23} particles, a definition that is inconsistent with the SI definition, as the mole is defined only as a number, and her response was coded F3. Admittedly this conceptualisation is defensible as an educational simplification as it helps learners visualise an abstract concept (Kolb,

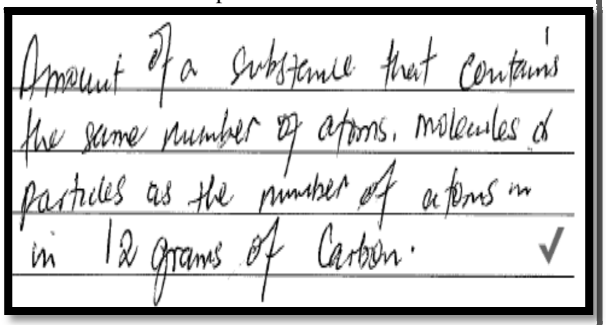
[18] In Strömdahl *et al.* (1994) the authors used F0 for mole as a proportion, F1 for the mole as a mass, F2 for the mole as a number and F3 for the mole as a unit.

1978; Strömdahl, 1996). However, with this conceptualisation of the mole, the empirical nature of Avogadro's constant is ignored, as is the fact that the mole as a counting unit is only an analogy and is not reinforced with students, thus contributing to reinforcing learner misconceptions (Cervellati, Montuschi, Perugini, Grimellini-Tomasini, & Balandi, 1982; Piepgrass, 1998). Based on this, and the reconceptualisation of the mole used in this study (see Appendix 4), this definition was also considered inappropriate, as it is inconsistent with the SI definition. However, as described later, teachers with this conceptualisation of the mole tended to adopt a more conceptual approach in their teaching strategies outlined in the Category E item of the TSPCK Instrument.

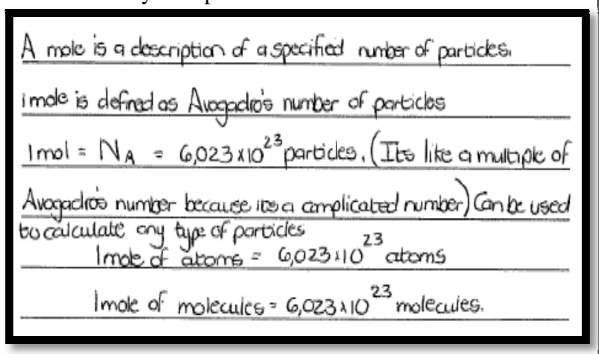
(3) Palesa's response, coded as F2, defined the mole as the amount of substance contained in the atomic mass in grams.

(4) Nomsa's response, coded as F1 defined the mole as a portion of a substance.

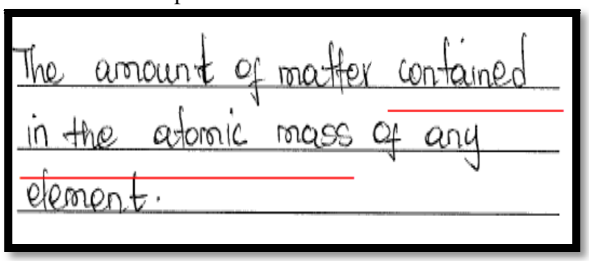
Example of a response that defines the mole as the unit for amount of substance.
V02 - Dumisani's responses coded as F4



Example of a response that defines the mole as a number.
V03 - Beverley's response coded as F3



Example of a response that defines the mole as a mass.
P03 - Palesa's response coded as F2



Example of a response that defines the mole as a portion of a substance.
V15 – Nomsa's response coded as F1

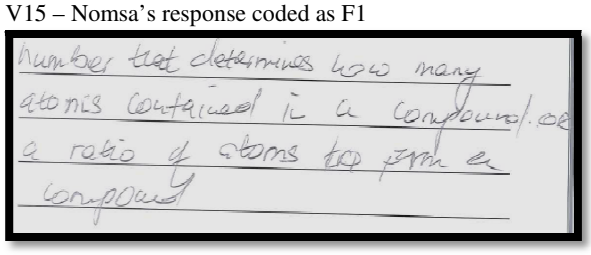


Figure 4.11: Examples of responses indicating respondents' conception of the mole

Of the thirty-one teachers who completed the CK Instrument, thirteen defined the mole as the unit for amount of substance, as it is defined in most chemistry textbooks (labelled as F4 in Figure 4.12). Therefore, more than half of the teachers had conceptions of the mole that were inconsistent with the SI definition as outlined by Strömdahl *et al.* (1994), with fifteen teachers defining the mole as a number labelled as F3 in Figure 4.12. This conception was also seen in some of the teachers' responses to the TSPCK items. Louise (P07) for example,

in her teaching strategy stated that: "For me it is repetition over a long time to drive in the concept that the number of moles represents a certain amount (meaning number) of particles." This is consistent with the findings that a greater portion of teachers work with the conception of the mole as a number (Strömdahl *et al.*, 1994). The mole was defined as a mass quantity, labelled as F2 in Figure 4.12 by two of the teachers. Again, this conception was evident in Palesa's response to the selection of a representation in Category D of the TSPCK Instrument where she stated that she would use Representation 3 to show learners that "one mole of an element has a mass equal to its atomic mass in grams". Only one of the teachers defined the mole as a portion of a substance (labelled F1). These findings are shown in the pie chart in Figure 4.12. These findings are consistent with surveys that have shown that teachers do not have a proper understanding of the mole (Nelson, 2013).

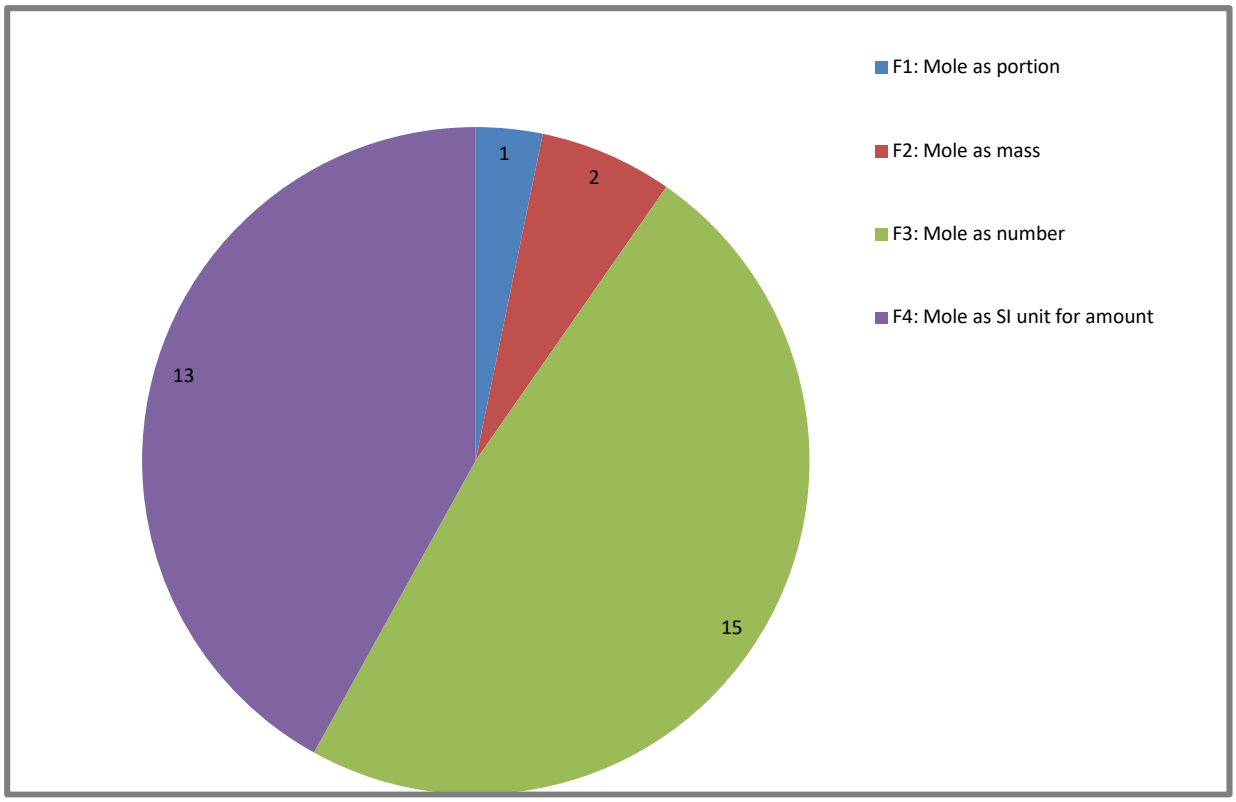


Figure 4.12: Pie chart of teachers' conception of the mole (N = 31)

This subsection looked at the responses to Question 2 of the CK Instrument, the definition of a mole. The responses to this question provided an indication of the teachers' conception of the mole. The influence of the teachers' conception of the mole in transforming their content knowledge in order to develop learner understanding was compared to the teaching strategies outlined in Category E of the TSPCK Instrument and how they would use the representation they selected for Category D of the TSPCK Instrument. Intuitively there emerged from the

correlation analysis and in-depth analysis of responses to the instruments teacher profiles for teaching stoichiometry. A cluster analysis was conducted using the scores for the five components of TSPCK, the CK score and the teachers' conception of the mole to investigate these groupings of teachers. The results of the cluster analysis are described in the next section.

4.6. Conceptualisation of the Mole and TSPCK Responses: Teacher Profiles

In the study conducted by Tullberg *et al.* (1994), they concluded that the approach teachers use in teaching stoichiometry is strongly bound to their own conception of the mole. Based on the qualitative analysis of the teachers' responses to the TSPCK Instrument, working mainly from the responses to the Category E item, teachers' conception of the mole and the correlation of the teachers' CK and TSPCK, apparent teacher profiles emerged. When observed values in the data indicated clustered data, the intrinsic structure of the groupings can be determined by cluster analysis (Fraley & Raftery, 1998). The cluster analysis, and the resulting teaching profiles are discussed in this section.

4.6.1. Cluster Analysis of Data from TSPCK and CK Instruments

The objective of cluster analysis is to assign observations to groups based on similarities in the variables of interest (Tryfos, 1998). The cluster analysis was conducted using a computer program designed to create market segments (Fripp, 2016). From the cluster analysis, three segments were identified (refer to Appendix 15). A full description of the cluster analysis is provided in Appendix 15. Based on the cluster analysis, Fripp (2016) recommends that the cluster with the best distribution of respondents across the segments, a low sum of the squared differences, or SSE between data points and means that make sense, be used to select the cluster output. Based on these recommendations, the three-cluster output was selected since it had the most respondents per segment, the SSE value was low and it confirmed the categories from the constant comparison analysis. Figure 4.13 illustrates the clustering segments and the central means for the three-cluster output. The complete cluster analysis is included in Appendix 15. As can be seen in Figure 4.13 there are three clustered segments. These represent the three groupings, determined by the central means of the variables for each of the five TSPCK component scores, the teachers' CK scores and their ordinal score

based on their conception of the mole. These groupings were used to develop the three teacher profiles for teaching stoichiometry summarised in Table 4.4.

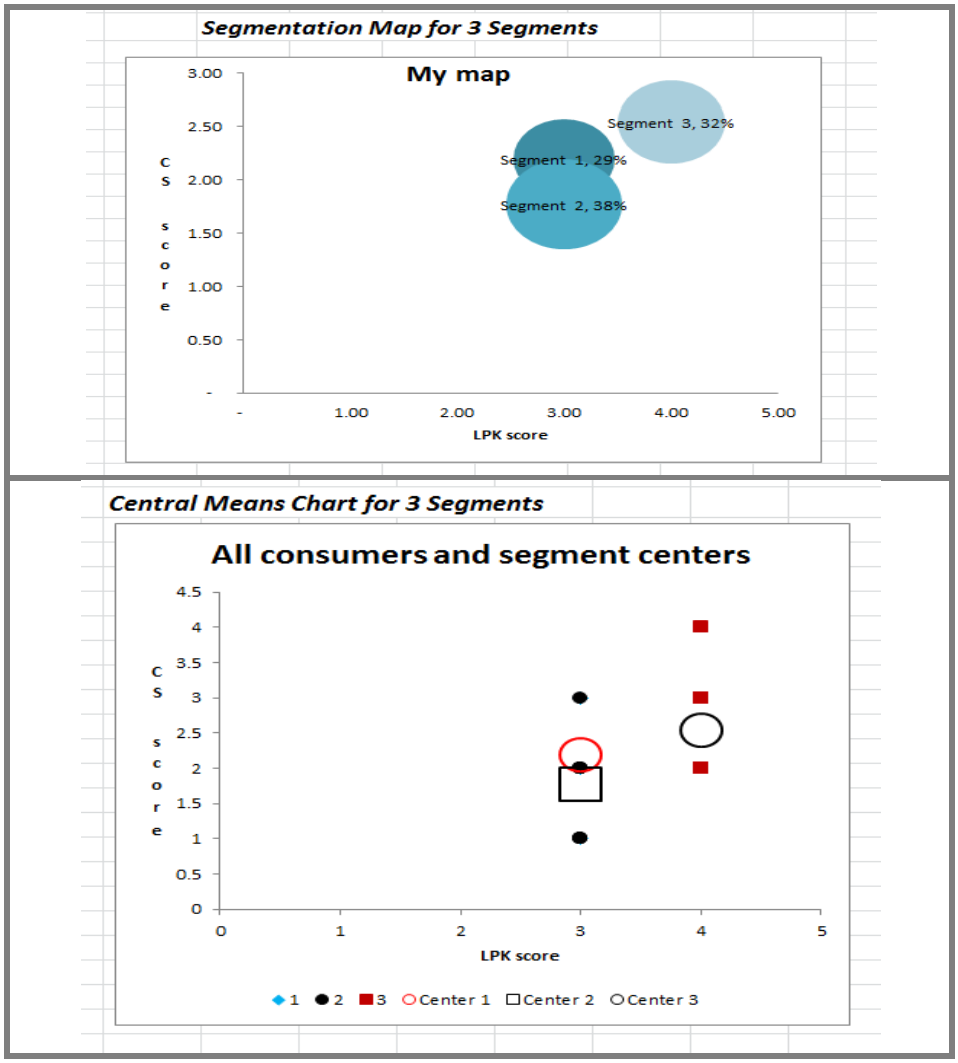


Figure 4.13: Segmentation maps and central mean graphs from cluster analysis

4.6.2. Teaching Profiles for Teaching Stoichiometry

The three teacher profiles were developed based on the segmentation map above in Figure 4.13. The first profile described as conceptually adequate are the teachers in segment 3.The teachers in segment 2, were described as algorithmically adequate and the teachers in segment 1 were described as algorithmically inadequate (see Table 4.4). The three-cluster segmentation, the constant comparison analysis and the correlation analysis were used to develop the teaching profiles for stoichiometry. However, for the purposes of this study, although all the TSPCK items were used in the cluster analysis only the REP and CTS items were used to describe the teacher characteristics for the three profiles. This was done based on the ideas presented by Tullberg *et al.* (1994), that teachers' conception of the mole

influences their teaching strategies. This data was used to complement the measurement of teachers' TSPCK to get a clearer picture of the quality of teachers' TSPCK. The results of the cluster analysis based on raw TSPCK component scores, teachers' conception of the mole and CK scores are described below.

The responses by the teachers for the item in Category E of the TSPCK Instrument on conceptual teaching strategies, were compared with their conception of the mole captured in the CK Instrument to determine if the identified clusters from the cluster analysis made sense. The three clusters and a summary of the qualitative analysis to describe the three teacher profiles are summarised in Table 4.4.

Table 4.4 includes:

- The teacher profiles. These are defined from studies related to students' ability to solve stoichiometric problems (Stamovlasis *et al.*, 2004, 2005). This is based on the assumption that students' ability is as a result of the transformation of the teachers' content knowledge into teachable forms (Shulman, 1987). Therefore students who can solve conceptual problems in stoichiometry have been taught conceptually. The first teacher profile is therefore labelled as conceptually adequate. The second teacher profile, labelled as algorithmically adequate is based on students who can solve stoichiometric concepts independently of developing conceptual understanding (Stamovlasis *et al.*, 2004, 2005). If students have developed competence in solving stoichiometric problems independently of developing conceptual understanding, it is assumed that teachers have taught them the algorithmic procedures to solve problems effectively. The last teacher profile is based on students' inability to solve stoichiometric problems and is labelled algorithmically inadequate.
- The raw scores for the REP and CTS items are included as teachers were grouped by the cluster analysis in terms of the similarity of respondents' scores to these items.
- A description from the qualitative analysis of the types of teaching strategies described by the teachers when answering the CTS item.
- The teachers' conceptions of the mole gleaned from the Question 2 of the CK Instrument. These are indicated separately for each teacher profile.
- The range of the CK scores.
- The last column has a list of respondents by code in each row in the table. These placements were confirmed by their placement in clusters from the cluster analysis.

Table 4.4: Teachers' teaching strategies and conceptions of the mole

Teacher Profile	REP Score	CTS Score	Teaching strategy for teaching limiting reagent	Mole concept	CK Score range	Teachers by code
Conceptually Adequate (Cluster 3)	3/4	3	Use of macroscopic analogies to illustrate that that particles of one reactant get used up. Does not provide procedure to follow.	F3	High CK	V05; V12; V17
	3	3	Use of macroscopic analogy to illustrate that different types of particles have different masses. Does not provide procedure to follow.	F3	High CK	P04, V01
	3	3	Use of macroscopic examples to illustrate that same number of different types of particles has different masses. Does not provide procedure to follow.	F3	High CK	V16
	3	3	Use submicroscopic representations to illustrate reacting ratios. Provides procedure to follow.	F3	High CK	P07
Algorithmically Adequate (Cluster 2)	3	2	Use of mathematical formula/symbolic representations to illustrate amount must be calculated from mass of reactants. May or may not provide a procedure to follow.	F4	Low to High CK	P01; P02; P06; V02, V04, V08; L01
	3	2	Use of mathematical formula/symbolic representations to illustrate amount must be calculated from mass of reactants. Provides procedure to follow.	F3	Moderate CK	P08; V09
	3	2	Use of mathematical formula/symbolic representations to illustrate amount must be calculated from mass of reactants. Provides procedure to follow.	F2	High CK	V11
Algorithmically Inadequate (Cluster 1)	2	2	Use of mathematical formula/symbolic representations to illustrate amount must be calculated from mass of reactants. Does not provide procedure to follow.	F3	Moderate to High CK	V06; V07; V14; C01; C02; L02
	2	2	Use of mathematical formula/symbolic representations to illustrate amount must be calculated from mass of reactants. Does not provide procedure to follow. May provide a rote definition of the mole	F4	Moderate CK	V13, L03
	2	1/2	Use of mathematical formula/symbolic representations to illustrate amount must be calculated from mass of reactants. Does not provide procedure to follow.	F2	Moderate to High CK	P03; C03
	2	1	Use of mathematical formula/symbolic representations to illustrate amount must be calculated from mass of reactants. Does not provide procedure to follow.	F1	Low CK	V15
Outliers	V03 (Beverley): Was placed in the Conceptually Adequate cluster as she had high CK and an F3 conception of the mole but only scored 2 for CTS as only used symbolic representations in her teaching strategies. P05 (Mbali): Was placed in the Algorithmically Adequate cluster with an F4 conception of the mole and had low CK but scored 3 for CTS as she included a macroscopic analogy to explain limiting reagents. V10 (Sindiswa): Was placed in the Algorithmically Adequate cluster with an F4 conception of mole and low CK score. Her overall TSPCK score was low due to her selection of big ideas.					

The first teacher profile for teaching stoichiometry that emerged from the data is described as conceptually adequate and were all clustered in segment 3 (see Figure 4.13). These teachers exhibited developing TSPCK in the TSPK components REP and CTS. They are also in the High TSPCK and High CK quadrants in Figure 4.10. In their teaching strategy, they included various types of macroscopic representations to help students understand limiting reagents together with symbolic representations and are recorded in the first three rows of Table 4.3. Linda (P07) used a sub-microscopic representation in her teaching strategy. Her description is in a separate row in Table 4.1. All of these teachers, with the exception of Beverley (V03) used two levels of representation in their teaching strategy. All of the teachers identified one mole as a number, Avogadro's number and that it is comparable to other counting units (Strömdahl *et al.*, 1994). This was evident in the way Geraldine (P04) used the analogy of comparing six elephants with six ants to help students understand that the same number of different particles have different masses to emphasise the importance of not using the mass to determine the limiting reagent. Jappie (V16) used actual samples to bridge the abstract nature of number of particles to the measurable quantity of mass (Strömdahl *et al.*, 1994). Although the conception of the mole as a number is inconsistent with the SI definition, these teachers used teaching strategies that include either macroscopic representations or submicroscopic representations to help students develop a conceptual understanding of stoichiometric concepts. It is also important to note that not all the teachers who conceptualized the mole as a number were included in this profile as they only used symbolic representations in their teacher strategy and were clustered in the second cluster (see Figure 4.13)

The second teacher profile for teaching stoichiometry to emerge from the data is referred to as algorithmically adequate. Most of these teachers had an F4 conception of the mole, with the exception of Linda (P08), Talia (V09) and Debbie (V11). Linda and Talia had an F3 conception of the mole and Debbie had an F2 conception of the mole. In most cases, with the exception of Mbali (P05), Tashin (P06), Dumisani (V02) and Sindiswa (V10), the teachers demonstrated moderate (between 60% to 69%) or high (70% and above) CK. All of the teachers scored a 3 for REP and a 2 for CTS. Although these teachers selected a representation and provided an explanation using two levels of representation in the REP item, with the exception of Mbali who included a macroscopic analogy, they only used symbolic representations in their teaching strategy.

The qualitative analysis of these teachers' responses confirms some of the characteristics of the teaching model used by teachers with the SI conception of the mole described by Tullberg *et al.* (1994). For example, most of the teachers listed the periodic table and if not explicitly stated, implied its importance in the interpretation of atomic mass, molecular mass and formula mass as an important pre-concept that needed to be taught before teaching the mole. In addition, all of the teachers responded to the item related to the importance of stoichiometry in terms of the use of the mole in quantitative analysis of chemical reactions and/or the industrial applications of stoichiometry and possibly motivate the use of the mole as a unit in the work of chemists (Tullberg *et al.*, 1994). The teaching approaches focus on using correct algorithmic methods with strategies that included using first principles, or algebraic methods including the ratio formula to solve stoichiometric problems (BouJaoude & Barakat, 2003; Chandrasegaran *et al.*, 2009) and focus on the physical quantity of amount (Tullberg *et al.*, 1994). All of the teachers, although focusing on the physical quantity of amount all referred to n as the 'number of moles' which is consistent with the ambiguities associated with the terms amount of substance and its unit the mole (Fang, Hart, & Clarke, 2015). The most striking difference between the South African teachers and the teachers in Sweden with an F4 conception of the mole is that, unlike their Swedish counterparts, teachers in South Africa do not use an experimental approach when teaching stoichiometry (Tullberg *et al.*, 1994).

Interestingly, the teachers with low CK in this profile and those who have a conception of the mole other than F4 all included a step-by-step procedure presented either explicitly, or implicitly implied in their teaching strategy. These teachers who conceptualised the mole as a number probably use a procedural approach since their students, whose conceptualisation of the mole mirrors theirs (Tullberg *et al.*, 1994), experience conceptual difficulties with this interpretation of the mole and therefore rely on rote learning and an algorithmic approach to solving stoichiometric problems (Fang *et al.*, 2015). The teachers who conceptualise the mole as the SI unit and have low CK probably do so since this is the definition provided in the curriculum document (Department of Basic Education, 2011a) and is an indication that understanding the mole concept goes beyond the simple articulation of the SI definition (Fang, Hart, & Clarke, 2014). Those therefore with low CK and who define the mole as the SI unit for amount of substance (P06, V02 and V10) possibly do not have a clear understanding of the concepts of atomic/molecular mass and molar mass, and more

importantly the connection between these concepts (Fang *et al.*, 2014). Hence the reliance on an algorithmic procedure, often found in textbooks, as students can follow a list of steps and solve stoichiometric problems correctly (BouJaoude & Barakat, 2000). Overall however, the teachers in this profile teach algorithmically and are probably able to successfully develop students' stoichiometric problem-solving skills without developing conceptual understanding (Stamovlasis *et al.*, 2004, 2005).

The third teacher profile for teaching stoichiometry to emerge from the data is referred to as algorithmically inadequate. This category has the greatest variance in terms of teachers' conception of the mole. The last four rows in Table 4.4 indicate the teachers who are placed in this category and they all used only symbolic representations in their teaching strategy, without providing students with a list of steps to follow. Each row indicates the teachers with different conceptions of the mole, from the SI conception of the mole as a unit for amount (F4), the mole as a number (F3), the mole as a mass unit (F2) and the mole as a portion of substance (F1). Although some teachers had a conception of the mole that is consistent with the SI definition (see Table 4.4), Fang *et al.* (2014) point out understanding the mole concept requires more than just being able to articulate the SI definition. These teachers scored a 2 for REP and either a 1 or 2 for CTS. Their CK scores ranged from low to high. In terms of the TSPCK score, with the exception of Palesa (P03), who has had experience with the construct of TSPCK and designing a TSPCK Instrument, all these teachers fall in the low TSPCK quadrants (see Figure 4.10). In their responses to the TSPCK instrument, they only focus on one level of representation in their explanations for the REP item and only use symbolic representations in their teaching strategy outlined in the CTS item.

The use of an algorithmic approach to teaching stoichiometry was also evident in the qualitative analysis of the 2 teachers who defined the mole as a mass unit (F2). This teaching approach confirms the teaching model described by Tullberg *et al.* (1994) and used by teachers who conceptualise the mole as a mass unit. The mole was defined as a portion of a substance by one teacher and this conceptualisation was also the least common in the study conducted by Strömdahl *et al.* (1994). Teachers who conceptualise the mole in this way see it as 'a portion of a substance having the property of reacting with other substances in whole value ratios (Strömdahl *et al.*, 1994). This is probably the reason Nomsa (V15) selected balanced chemical equations as a big idea. She also selected Representation 3 that included a balanced chemical equation and the reason she stated that stoichiometric calculations was a

difficult concept to teach was because students "don't balance their reactions". The teachers in this profile therefore are probably unable to develop even students' algorithmic or procedural knowledge in stoichiometry.

This section has discussed teacher profiles based on their strategies for teaching stoichiometry and their conception of the mole. These teacher profiles are based on a cluster analysis (see Appendix 15). A qualitative analysis of the teachers' responses to the Category E item CTS in the TSPCK Instrument was compared with their conceptualisation of the mole and the majority of teachers, even with the SI conception of the mole teach algorithmically. It is apparent that teaching approaches are based on teachers' conception of the mole; however, not all teachers that can articulate the SI definition for the mole necessarily use teaching strategies that help learners bridge the macroscopic property of mass with atomic concepts at the submicroscopic level (Fang *et al.*, 2014, 2015). From the qualitative analysis of the teachers' responses, it was evident that teachers with a conception of the mole as a number used teaching strategies that incorporated macroscopic representations with symbolic representations and teach conceptually.

4.7. Summary

This chapter has described the analysis of the responses to the TSPCK Instrument and the CK Instrument of experienced Physical Science teachers. The chapter therefore speaks to the first research sub-question of the quality of experienced physical science TSPCK in stoichiometry. The importance of determining the quality of teachers' TSPCK is linked to the purposes of designing effective professional learning activities that speak to effective practices in teaching (Desimone, Porter, Garet, Yoon, & Birman, 2002). Therefore, in order to design an effective professional learning activity that develops teachers' TSPCK in stoichiometry, an overview of the quality of teachers' TSPCK was required. The qualitative analysis of the instruments provided evidence that the teachers' TSPCK was centred around basic to developing TSPCK. The qualitative analysis of responses indicated that, although teachers performed well in the category REP, the majority of teachers scored below the group mean which was an indication of a lack of integrating the components. The latter was evident in their responses to the item on conceptual teaching strategies.

Most teachers focused on the use of symbolic representations when describing a teaching strategy and only a small number of teachers integrated macroscopic representations into

their teaching strategies. The quality of teachers' CK was also outlined, with most teachers having adequate levels of CK. However, many teachers struggled with conceptual questions that used submicroscopic representations (see Appendix 14). The correlation between teachers' TSPCK and CK was described and based on teachers' placement in the quadrants of TSPCK and CK, teacher profiles were identified. In some cases, this placement required a closer look at responses to either the CK Instrument or the TSPCK Instrument to justify the placement of a handful of teachers in the quadrant with high TSPCK and low CK. This was attributed to their experience and knowledge in designing TSPCK instruments to measure TSPCK in chemistry topics. Since teachers' conception of the mole influences the way they teach stoichiometry, this was also described (Tullberg *et al.*, 1994).

Based on the relationship between TSPCK and CK, patterns emerged through cluster analysis and three teacher profiles were identified. Interestingly, the teachers who used a more conceptual approach conceptualised the mole as a number. However, the categories that emerged indicate that the majority of teachers require some form of professional development in the teaching of stoichiometry. The analysis of the responses helped inform the professional learning activity described in the next chapter. In Chapter 5, the formation of the PLC is described, as are the goals, and a description of the Learning Study.

CHAPTER FIVE

The Learning Study as a Professional Development Activity

This chapter provides a comprehensive descriptive account of the Learning Study as a professional development activity. The first part of this chapter is aimed at providing a working definition of a Professional Learning Community. It then describes the relationship between the teachers in the Professional Learning Community and the relationship between the teachers and the chemistry education experts. The purpose of the Professional Learning Community is then described before an outline of the structure of the collaboration is provided. Each of these aspects is linked back to the working definition of a Professional Learning Community used for this study. The goal-direct activity of the Professional Learning Community is then described. Firstly, the planning workshop is outlined and provides details of how the team were introduced to the construct of TSPCK, using episodes from my own classroom teaching. The chapter then provides an outline of the different aspects of the Learning Study, from planning the lesson using an adapted content representation for the components of TSPCK, and then teaching the lesson and discussing the lesson to improve it through four cycles. The chapter highlights aspects of the discussions of the Professional Learning Community to provide a sense of the dialogue of the team since the study aimed to investigate how this contributed to teacher learning. The chapter ends by outlining the activities that occurred after the Learning Study related to interviewing the teachers about the lessons they taught. The chapter also states at which points the teachers were pre-tested and post-tested using the TSPCK instrument to measure the change in their TSPCK through participation in the Learning Study.

5.1. Introduction

The previous chapter provided an account of the baseline quality of a sample of experienced Gauteng teachers' quality of topic-specific PCK and content knowledge in the topic of stoichiometry. Instruments were designed and validated for this study (Malcolm, 2015) since they were required to measure the change in TSPCK in the topic of stoichiometry. The results from the analysis of the teachers' responses indicated that there were a number of problems related to the teaching of stoichiometry. Firstly, based on the qualitative analysis of teachers' responses to the item on curricular saliency (see Appendix 8), just over half of the teachers

identified the mole concept as a big idea in stoichiometry. Just over half the teachers also selected stoichiometric calculations as a big idea which provided evidence of teaching stoichiometry algorithmically. This was confirmed through the qualitative analysis of teachers' responses to the conceptual teaching strategy item where the majority of teachers provided an algorithmic explanation to help correct the learner errors described in Chapter 4. From the qualitative analysis of the conceptual teaching strategy item it was also evident that many teachers only used symbolic representations and a handful of teachers integrated the use of the three levels of representation first described by (Johnstone, 1991). Most teachers did not use examples or do demonstrations or experiments when teaching stoichiometry. Finally, the term amount of substance was not used by teachers in their responses and they referred to either the mole or number of moles. This problem has been identified in the literature as contributing to student difficulties (Furio, Azcona, & Guisasola, 2002; Packer, 1988).

The problems indicated above were, in my mind, aspects that I brought into the planning of this study as problems that needed to be incorporated into the professional learning activity that was central to this study. In Chapter 3, I outlined my role as the researcher. Since the professional learning activity, which is described in this chapter, included forming a Professional Learning Community, my role was more than just researcher. I was working with the participants to develop their professional practice (Cole, 1989; Wagner, 1997). I was also the facilitator of the PLC (Brodie, 2013; Brodie & Shalem, 2011). Therefore, as described in Chapter 3, this linked me to the participants and because of what I had learned in developing the instruments for this study, I had very clear ideas of which aspects to focus on in the PLC. There was a degree of subjectivity (Toma, 2000). This chapter describes the formation of the PLC, and developing and improving the lesson plan, that served as the focus for the Learning Study developed by the PLC.

5.2. Forming the Professional Learning Community

In the South African context, the policy related to teacher education and development aims at equipping teachers, with the support from educational stakeholders, to be instrumental in their own professional development (Department of Basic Education & Department of Higher Education & Training, 2011b). Prior to 2011, there was no agreed-on approach for professional development to improve the quality of science education (Clynick & Lee, 2004). The

professional development policy prior to 2011, according to Steyn (2008), did not make provision for measuring the impact of professional development on classroom enactment and ignored important theories of learning such as Wenger's social learning theory. However, there was the realisation by government that teachers need to 'strengthen their subject knowledge base, pedagogical content knowledge and teaching skills' (Department of Education, 2006, p. 17).

Professional learning is not necessarily confined to in-service programmes and teachers can learn from each other (Floden, 2001). The connections between colleagues, or professional conversations in social contexts for constructing and negotiating meaning, and critically scrutinising practice in which teachers discuss ways to improve instruction in communities of practice, is essential if the objective of professional development is to improve classroom enactment rather than implement new policies (Elbaz-Luwisch & Orland-Barak, 2013; Floden, 2001; Steyn, 2008). Professional development should therefore both respect and acknowledge what teachers know, and provide teachers with opportunities to articulate their own purposes and concerns, to broaden their own understanding of education, teaching and learning (Avalos, 1998). Symington and Osborne (1985) note that, for experienced teachers, professional development often fails to meet their needs. According to Ramnarain and Fortus (2013), there is therefore a need to tailor professional development activities to meet the needs of South African teachers. Kriek and Grayson (2009) also highlight the need for longer, sustained and intensive professional development activities, rather than short, once-off programmes. To teach effectively, teachers need to continuously inquire into and improve their own teaching and, according to Hargreaves and Fullan (2012), this cannot be done as an isolated individual but rather as a part of a team in a school or community.

According to H.-J. Lee (2005), the professional development of teachers should also meet the following criteria for the best outcomes. The criteria include providing activities that demonstrate new ways to teach and learn, use a team approach, build the capacity of teachers, provide time for reflection and evaluate the effectiveness and impact of the activities. Professional development that focuses on the design of and reflection of artefacts of practice, such as learner thinking, learner tasks or instructional practices, and promotes the creation of professional learning communities, are key features of successful professional development programs (Borko, 2004; Brodie, 2013; Brodie & Shalem, 2011). For this study, the focus was on the continuing professional development of experienced, practicing teachers. Therefore the need for a professional development intervention that considered the needs of experienced

teachers, that provided a social context for learning which critically examined classroom enactment as part of a team and allowed for reflection, required the formation of a Professional Learning Community.

5.2.1. Toward a Working Definition of a Professional Learning Community

Teaching is often conducted within a state of professional isolation and, in South Africa, teachers are not encouraged to share educational practices or collaborate (Botha, 2012; Hargreaves & Fullan, 2012). Teachers are able to exercise their discretionary judgement in their classroom but are often cut off from valuable feedback from their peers, that would help those judgements be wise and effective. However, collaboration, in fact, increases not only teachers' ability to analyse their classroom enactment but improves a teacher's enactment in the classroom itself (Briscoe & Peters, 1997; Brodie, 2013).

It is therefore generally accepted that teachers improve when they collaborate with and learn from other teachers, since such communities are viewed as relevant and authentic spaces to critically, collaboratively and supportively create knowledge, and examine their roles and practices (Elbaz-Luwisch & Orland-Barak, 2013; Hargreaves & Fullan, 2012). In terms of PLCs, the vision of teaching builds on both the individual and collective capital of the profession in order for teachers to become more effective in their practice, and so to improve student learning and achievement (Hargreaves & Fullan, 2012). Within this vision, good teaching is viewed as a complex process that is technically sophisticated and difficult, perfected through continuous improvement and involves wise judgement informed by evidence and experience (Hargreaves & Fullan, 2012; Loughran, 2010). In order to learn from practice or experience it is also essential to be engaged in reflective practice (Hargreaves & Fullan, 2012).

According to Loughran (2010) reflection is a specialised form of thought that lies at the heart of professional practice. Reflective practice is more than simply thinking about a teaching episode or event, and has two important aspects (Hargreaves & Fullan, 2012; Loughran, 2010). The first is reflection *in* action, in the action of teaching, when you have to think about what you are doing, even as you are improvising it. Reflection *on* action is reflection after teaching, once the practice has finished. According to Hargreaves and Fullan (2012), teachers that are able to get reflection on practice correct are better enabled to effectively reflect in action. Therefore it is not surprising that the development of teacher knowledge and teacher

learning has shifted focus to community settings for fostering teacher development (Elbaz-Luwisch & Orland-Barak, 2013).

But what is a Professional Learning Community? There is no universal definition for a PLC, but the general consensus is that, when a group of teachers share and critically interrogate their practice in a reflective, collaborative, inclusive, learning-orientated and growth-promoting way, one exists (Stoll & Seashore Louis, 2007). The term PLC is underpinned by three important aspects as suggested by the term. The word 'professional' implies that the community's work is underpinned by a specialised and technical knowledge base (Stoll & Seashore Louis, 2007). Central to this is the idea of being guided by experienced collective judgement, in collaborative improvements and decisions, that are informed by scientific and statistical evidence, through challenging conversations about effective and ineffective practice (Hargreaves & Fullan, 2012).

The word 'learning' indicates that the emphasis of such a community is to move beyond the idea of a traditional community that often has a limited interest in changing their practice, but rather with the objective of improving by working together towards a common understanding of concepts and practices. Through professional conversations, knowledge is constructed through social interactions, hence learning is viewed from a social constructivist point of view and individual learning is mediated by the social discourse represented in the ideas of Vygotsky and Wertsch (Elbaz-Luwisch & Orland-Barak, 2013).

At the heart of a PLC is the word 'community', which implies a cohesive group with a collective responsibility for a common educational purpose with the express intent of professional learning within the group that does not only focus on individual teacher's learning, but collective learning to improve practice (Hargreaves & Fullan, 2012; Stoll, Bolam, McMahon, Wallace, & Thomas, 2006; Stoll & Seashore Louis, 2007). In other words, in a PLC, what teachers learn individually and bring to their classrooms is supplemented by the understanding of concepts and practices held in common as part of a team (Reichstetter, 2006; Stoll & Seashore Louis, 2007). In fact, the community is seen to learn as a whole, since the community changes its practices in ways that cannot be reduced to what individuals learn (Marton & Trigwell, 2000). This is an extension of the view of teacher knowledge and teacher learning, since it speaks to the intellectual, personal and professional development of teachers in a community setting (Elbaz-Luwisch & Orland-Barak, 2013).

Generally it is assumed, particularly in the literature related to PLCs, that only teachers within a school are members of the community (Bolam, Stoll, & Greenwood, 2007). However, for this study, the opportunity to form a PLC was with high school teachers from different schools. These teachers were already committed to their professional development in the Master's programme with the requirement of a research component. This, therefore, provided the opportunity to examine the improvement in teacher knowledge and teaching through collaboration in the planning and teaching of a difficult topic like stoichiometry. Therefore, since the teachers in the Master's programme are not from the same school, a broader definition for a PLC was required.

According to Stoll and Seashore Louis (2007), there is a need for an expanded approach to PLCs, to include broader membership that extends among schools: to include networks of schools. Key to extending the membership of a PLC in this way is that the purpose remains the same, which is to enhance effectiveness as professionals to benefit student learning (Stoll *et al.*, 2006; Stoll & Seashore Louis, 2007). Within this context, C. Mitchell and Sackney (2007) view a PLC as a place of and for connections, relationships, reciprocity and mutuality. Such collaboration, based on learning principles that enable effective practice to be developed, has the potential to contribute to improving student learning and raising student achievement in schools (Earl & Katz, 2006; C. Mitchell & Sackney, 2007). Collaboration between teachers from a network of schools in a PLC is referred to as network learning (Jackson & Temperley, 2007). According to Jackson and Temperley (2007), network learning occurs when teachers from individual schools come together in a group and engage in a purposeful and sustained developmental activity, informed by the public knowledge base, their own practitioner knowledge or know-how, and co-constructing knowledge together. The expansion of PLCs could also move beyond schools to include members from the wider community (Stoll & Seashore Louis, 2007). In this case, science education researchers, well informed by the public knowledge base related to teacher knowledge and development, would be an invaluable addition to the network of the PLC.

An effort has been made above to highlight important characteristics or features of PLCs in order to generate a working definition for this study. The first is that we formed a team of members drawn from a network of schools and the wider science education community to critically and reflectively interrogate teaching practice using a specialised knowledge base (Hargreaves & Fullan, 2012; Reichstetter, 2006; Stoll & Seashore Louis, 2007). Secondly,

the critical and reflective interrogation of practice is tackled collaboratively with the educational purpose to improve effectiveness as professionals to benefit student learning (Hargreaves & Fullan, 2012; Reichstetter, 2006; Stoll & Seashore Louis, 2007). Thirdly, the collaboration is orientated around network learning through the social interactions and discourse of the community (Elbaz-Luwisch & Orland-Barak, 2013; Jackson & Temperley, 2007; Stoll & Seashore Louis, 2007).

Based on these features or characteristics, the following working definition was therefore adopted for this study:

> *A Professional Learning Community is made up of a team of members drawn from a network of different schools and science education experts collaborating to improve effectiveness as professionals and benefit student learning through the critical and reflective interrogation of practice using a specialised knowledge base and orientated around network learning through social interactions and discourse of the community.*

5.2.2. Establishing the Relationships in the Professional Learning Community

In the previous sub-section, the need to expand PLCs beyond teachers in a school to include teachers from different schools and members from the broader community was discussed, in order to provide the working definition for a PLC above. Key to this definition is a team of members which emphasises mutually supportive relationships (Bolam *et al.*, 2005; Reichstetter, 2006). The team comprised of three teachers from different schools, or a network of schools, completing the research component of their Master's degree and had completed the instruments in Phase I of this study. Each teacher was allocated a research supervisor after consultation with the students and the relevant staff members at the University, which, as experts in science teacher education and chemistry, also formed part of the PLC. A brief biography of each teacher and their respective supervisors, as knowledgeable peers, was provided in Chapter 3. In this sub-section, the creation of productive relationships between the team members collaborating, which Brodie (2013) reports as a key characteristic of successful PLCs, is discussed.

Teacher Participants from the MSc Programme form a Network of Schools

For this study, the opportunity to draw participants from the group of Masters students was advantageous, since, generally, schooling systems are fragmented with little opportunity for school-to-school collaboration or forming a network (Jackson & Temperley, 2007). Furthermore, there is generally a lack of a shared professional identity among teachers, a common belief about themselves as teachers and common expectations of their colleagues that act as a barrier to such collaboration (A. Mitchell, 1997). These barriers were, however, negated to some extent because the teachers completing the Masters' programme at the university were already engaged in professional development, aimed at creating opportunities for career development, professional renewal and developing an understanding of current issues and problems in science education (Essien & Oyoo, 2016). In addition, the teachers had already completed the coursework for the programme the previous year. These classes are generally presented in a way that encourages interaction and discussion among students in order to meet the course outcomes, which include critically engaging with current theories and methods in science education, critically commenting on academic writing and participating in debates in science education. Therefore, an informal network through their participation in the Master's programme had already been established, which needed to be formalised for the research component of their degree.

The existing relationship described above was important, since, to ensure collaborative cultures, the first step, according to Hargreaves and Fullan (2012), is about developing trust and relationships, usually in an informal way, and this requires time. The interaction in the course work over the previous year had therefore developed the relationship between the participant teachers, and all that was required was to formally convene a PLC from the participants from different schools. However, a shared curricular-focused vision with the purpose of improving classroom enactment to benefit student learning is central for creating a successful PLC (Reichstetter, 2006; Stoll & Seashore Louis, 2007). A key aspect of the research at the Marang Centre for Mathematics and Science Education is to leverage initiatives towards improving teaching in schools and linking good PCK to student outcomes (Rollnick & Mavhunga, 2015). The formation of a PLC of a network of teachers conducting research in the PCK thrust ensured this common purpose.

Supervisors of MSc Teacher Participants as Experts

Generally the role of supervisors in the research component of the Master's programme is to assist students in preparing a research proposal, during the research and write-up of the research report (Essien & Oyoo, 2016). The assistance typical of supervision usually includes support, guidance, encouragement and advice in the research process (Gill & Burnard, 2008). All three supervisors, however, have experience in researching the development of PCK of practising teachers through engagement in self-studies, through expert input to teach new topics or in pre-service teachers through the explicit teaching of the transformation of a topic. The supervisors could therefore provide instruction as experts brought into the PLC (Briscoe & Peters, 1997; LaFee, 2003) on PCK, chemistry education and teacher education. This also ensured that the participating teachers had access to other researchers in the field (Bolam *et al.*, 2005) beyond just the typical access characterised by the supervision process (Gill & Burnard, 2008). The three supervisors of the participating Masters students therefore represented a potentially rich resource for input in planning the lesson in chemistry, discussing the lesson and in assisting the teachers to reflect on the lesson in a collaborative setting (Briscoe & Peters, 1997). There was therefore a shared purpose among the members of the PLC, including me, in conducting this study. The shared purpose of the community is outlined in more detail in the subsection below.

5.2.3. The Purpose of the Professional Learning Community

This chapter began by developing a working definition for a PLC. The definition included the goal of the collaboration, which was to '*improve practice as professionals and benefit student learning*'. An effective PLC has a shared mission, vision, values and goals (Reichstetter, 2006). The shared vision is the commitment of teachers to student learning and improvement in meeting student needs (Hord, 1997; Reichstetter, 2006). Values and beliefs have been reported to guide teachers' individual classroom practice (Gudmundsdottir, 1990), influence teachers' decision-making and behaviour (Thomson, Di Francesca, Mcintyre, Carrier, & Zulli Lowe, 2013) and influence what is learnt by teachers during professional development programmes (Desimone, 2009). In a PLC, the mission or purpose is to ensure that all participants learn through the collaborative, interdependent practice of the team that have agreed on goals, the learning outcome agreed on for all participants and that teaching and instruction are aimed at improving student performance (Bolam *et al.*, 2005; Reichstetter,

2006). In this subsection, the aspects related to the vision, mission, values and goals of the PLC are described.

According to Bolam *et al.* (2005), during the initiation stage of forming a PLC, in creating a shared vision and mission, the emphasis is on espoused norms and values. These norms and values were, in a sense, taken as basic since values are integral to teaching excellence, and teaching without values would be characterised by indifference, which would translate into classroom enactment as an absence of concern for student achievement (Gudmundsdottir, 1990). These values and norms are illustrated in the words of the participating teachers from the transcript of our first planning meeting.

Tendani (line 88)**:**	*My … my strategy when I'm teaching Grade twelve's ne, my strategy is that, like I said, I'm teaching for exams. They must know that each question has got a definition. First memorise and then you'll know. That's my advice to them.*
Sizwe (line 133):	*I think it's very important you want to create understanding, in that we need to find new ways of improving stoichiometry conceptually. Even at university you will find that there are so many dropouts because of people who memorise a lot. Schools produce very good results, 97% physical science, but there are very few of those learners will go beyond first year at university because of that.*

Tendani's concern for his students' passing their exams is evident. He emphasises the need for his students to memorise the definitions. Within the context of this conversation, Sizwe's concern for students' performance at a tertiary level is clear. Although both teachers might have individual preferences in terms of teaching approaches, both have a sense of direction and purpose in terms of wanting their students to perform (Dooner *et al.*, 2008; Gudmundsdottir, 1990). This initial overlapping of a shared value base provides the framework for the shared, collective and ethical decision-making required for effective collaboration (Dooner *et al.*, 2008; Stoll *et al.*, 2006).

Central to the effective collaboration in a PLC is goal-directed action in which people work together on a special topic, to analyse practice in order to improve student performance (Jaworski, 2008; Reichstetter, 2006). According to Brodie (2013), the focus, or content that relates to the instructional core and deals with a problem of practice based on student needs is essential for effective collaboration. The initial goal, based on the conceptualisation of this study, related to student difficulty with stoichiometry and focus by teachers on an algorithmic approach to teaching stoichiometry, was to collaboratively develop a revision lesson for Grade eleven learners. The topic for the collaboration was initially negotiated with the

supervisors of the participating teachers in a meeting, who then discussed the idea with their Masters students. A second meeting, this time with both supervisors and the participating teachers was arranged in order to agree on the essential learning outcomes, or what we wanted students to learn, based on a review of the curriculum and on discussing the common means by which this goal would be achieved (Dooner *et al.*, 2008; DuFour, 2004; Reichstetter, 2006).

In order to achieve the goals of a PLC the team members' interdependence becomes centred on their practice, or common means and the formalisation of the practices of the community (Dooner *et al.*, 2008; Hoadley, 2012). The shared vision and willingness to cooperate must be translated into a system of rules, that revolve around the professional activities of learning, decision-making, planning and problem-solving, focused on obtaining data about student performance that can serve as a feedback mechanism for improving teaching and learning (Bolam *et al.*, 2005; Hord, 1997). Effective collaboration benefits from structure, or supportive conditions, such as deliberate arrangement of meetings, structures and protocols in which all parties are committed to building better relationships (Hord, 1997; C. Mitchell & Sackney, 2007). In the next subsection the structure of the collaboration is outlined.

5.2.4. The Structure of the Collaboration in the Professional Learning Community

As a community of practice of practitioner-researchers, the members of the community engage in joint activities and discussion (Wenger, 2011). When establishing such communities, there is a need to develop the interdependence of the team members that is centred on a collective obligation, and shared actions that include common means and common ends to 'get the job done' (Dooner *et al.*, 2008, p. 566). For our PLC, the common end was an explicit focus on learning and development of teacher knowledge in the topic of stoichiometry (Hoadley, 2012). The development of the collaborative culture, therefore, required a structure to be established to achieve the common end and ensure learning for all (Dooner *et al.*, 2008; DuFour, 2004). In this subsection, the joint activities, the structure and common means to develop our collaborative culture are outlined.

The first stage in developing a common means in a PLC is to ensure team members have a common understanding of the proposed structure of the collaboration (Stoll *et al.*, 2006). Therefore, in order to develop the teams' interdependence centred on a common means of our

practice, assigned readings were shared electronically with the participants in order to conduct a literature review (Dooner *et al.*, 2008; Norwood, 2007). The assigned readings, related to Lesson Study and Learning Study as systematic inquiries into teaching practice to develop professional knowledge (Fernandez, 2002; Pang & Ling, 2012). By reviewing the literature, the participating teachers gained an insight into what Hord (1997) refers to as the 'how' aspect of the team members coming together to collaborate, an important aspect of the supportive conditions required for an effective PLC. The assigned readings made it evident that classroom enactment would be shared and discussed, thereby requiring a willingness to accept feedback when discussing practice (Fernandez, 2002; Hord, 1997; Lewis, 2000). The assigned readings therefore laid the foundation in terms of the PLCs plan of action. This plan of action included meetings to discuss and reflect on practice as a basic feature of the collaboration (Jaworski, 2008) *to improve effectiveness as professionals and benefit student learning*.

With the 'how' aspect of the supportive conditions necessary for effective collaboration in a PLC established, the focus shifted on to 'where' and 'when' we would come together as a team (Hord, 1997) for reflective dialogue and collective inquiry (Reichstetter, 2006), that *orientated around network learning through social interactions and discourse of the community*. Generally, time is a constraint for both PLCs and practitioners engaged in either Lesson or Learning Study (Chokshi & Fernandez, 2004; Fernandez, 2002; Hargreaves & Fullan, 2012). However, since our PLC was formed as a practitioner-based collaborative action inquiry (Yorks, 2005), with each participant researching their practice as part of their Master's degree, with supervisors in a supportive role, being accessible and available at appropriate times (Gill & Burnard, 2008) was advantageous. The time to meet and talk was therefore part of the team's collective obligation of co-inquiry into their practice motivated by each individual's desired end of completing their own research project (Dooner *et al.*, 2008; Hord, 1997). For our PLC, time constraints were rather on completing the required goal-directed action in the timeframe, as stipulated by the Department of Education which granted permission to do the research in schools (see Appendix 1). Our goal-directed action included a workshop, described in detail in the next section of this chapter, to familiarise the teacher participants with topic-specific PCK and planning the first lesson.

Our goal-directed action then included conducting a Learning Study, which is described in more detail in the next section. Briefly, this included piloting the lesson and diagnostic tests,

meeting to analyse classroom enactment and student performance to make improvements based on the feedback before teaching the lesson again. This was done through another three cycles of planning and teaching the lesson. This required negotiation with supervisors, as the meetings needed to fit into their busy schedules, and the teacher participants, since they had to negotiate with their students to attend the revision lesson on a Saturday and find time to meet with me to finalise the lesson plan after the discussion meetings. The action-plan is described in more detail in the next section but basically it was planned to ensure a '*critical and reflective interrogation of practice using a specialised knowledge base and orientated around network learning through social interactions and discourse of the community'*. The schedule of this goal-directed plan is summarised in Table 5.1 below.

Table 5.1: Schedule of goal-directed collaboration of Professional Learning Community

Date (2015)	Activity	Key outcomes
Saturday (May 23rd)	Planning Workshop with team	• Familiarise participants with construct of TSPCK • Developing CoRe for the Big Idea for the lesson
Friday (May 29th)	Planning Meeting with team	• Discussion of conceptual teaching strategies in CoRe for Big Idea for lesson • Generate lesson plan based on the CoRe
Wednesday (July 15th)	Piloting lesson by researcher	• Teach the pilot lesson to a group of Grade 11 learners • Assess student achievement using pre-test & post-test
Tuesday (July 28th)	Discussion Meeting with team	• Analyse practice and student performance • Reflect on lesson and discuss improvements
Tuesday (August 4th)	Planning session with Sipho	• Discussion of improvements and generate lesson plan • Arrange resources for lesson
Saturday (August 8th)	Teaching of lesson by Sipho	• Teach the revised lesson to a group of Grade 11 learners • Assess student achievement using pre-test & post-test
Tuesday (August 25th)	Discussion Meeting with team	• Analyse practice and student performance • Reflect on lesson and discuss improvements
Tuesday (September 1st)	Planning session with Tendani	• Discussion of improvements and generate lesson plan • Arrange resources for lesson
Saturday (September 5th)	Teaching of lesson by Tendani	• Teach the revised lesson to a group of Grade 11 learners • Assess student achievement using pre-test & post-test
Tuesday (September 15th)	Discussion Meeting with team	• Analyse practice and student performance • Reflect on lesson and discuss improvements
Thursday (September 17th)	Planning session with Sizwe	• Discussion of improvements and generate lesson plan • Arrange resources for lesson
Saturday (September 19th)	Teaching of lesson by Sizwe	• Teach the revised lesson to a group of Grade 11 learners • Assess student achievement using pre-test & post-test
Tuesday (September 29th)	Discussion Meeting with team	• Analyse practice and student performance • Reflect on lesson and discuss improvements

The structure of the collaboration as outlined in Table 5.1 aimed at developing network learning. According to Jackson and Temperley (2007), network learning occurs when the following four distinct learning processes are present. Through the planning and discussion meetings as part of the collaboration, the aim was that firstly, the team members learnt from one another by capitalising on our individual differences and diversity through sharing our knowledge, expertise, experience and practice. Secondly, by learning with one another as

individuals, the team would learn together and co-construct learning that included collaborative practitioner enquiry and collaborative learning about recent research. Thirdly, there would be meta learning, in that the teacher-participants would learn about the process of their own learning in researching their own classroom enactment and TSPCK development. Lastly, that the participants from different schools would be learn on behalf of other individuals in their schools or in the network, or part of the wider system. This implies that learning does not only take place between individuals in the group, but that there is a transfer of learning that takes place to other teachers in the participant's school.

This subsection began with a description of describing a PLC within the context of teacher professional development, and since there is no universal definition for a PLC (Stoll & Seashore Louis, 2007) a working definition for this study was developed. For effective collaboration amongst individuals in a PLC, a relationship is required, which can be built on through participation (Bolam *et al.*, 2005; Hoadley, 2012) and the initial relationships between the various *team members* was described. The purpose of the PLC was outlined, including the shared vision of *collaborating to improve effectiveness as professionals and benefit student learning*. Finally, the brief description of the structure of the collaboration points to the goal-directed action to allow for the *critical and reflective interrogation of practice using a specialised knowledge base and orientated around network learning through social interactions and discourse of the community* which is described in detail in the rest of this chapter.

5.3. The Goal-directed Action of the Professional Learning Community

Science educators are part of a discrete domain in the education system with a shared competence, the teaching of science, which distinguishes them from other teachers (Clynick & Lee, 2004; Wenger, 2011). Within the South African context there is a need to develop competent science teachers and strengthen their conceptual knowledge, PCK and teaching skills, and improve student performance in science (Clynick & Lee, 2004; Department of Education, 2006). A group of experienced Physical Science teachers, part of a community of practice are involved in the joint activity (Wenger, 2011) of professional development in the university's M.Sc programme. The teachers had the shared interest of completing their research projects to explore the potential of working together and forming a PLC (Dooner *et*

al., 2008). In the previous section, a working definition for a PLC specific to this study was formulated. The aspects of this definition included that a PLC *is made up of a team of members drawn from a network of different schools and science education experts*, since the teachers were from different schools and their respective research project supervisors were the experts in science teacher education. Effective PLCs also require supportive conditions, the 'how' or goal-directed plan and the 'where' and 'when' structure (Hord, 1997; Jaworski, 2008) which was outlined in the schedule in the previous section. This structure aimed at providing a learning environment that engaged the community members in a shared learning enterprise focused on a particular topic through participation to improve teaching practice (Buysse, Sparkman, & Wesley, 2003; Chalmers & Keown, 2006; Handley, Sturdy, Fincham, & Clark, 2006) It is the goal-directed plan of collaboration and the supportive conditions in which *the critical and reflective interrogation of practice using a specialised knowledge base and orientated around network learning through social interactions and discourse of the community* that this section will describe.

5.3.1. The Planning Workshop

The planning workshop was scheduled as the first official meeting of our PLC (see Table 5.1). We had met on two previous occasions where my study had been explained to the participating teachers and informed consent forms had been signed. In turn, each of the teachers had also outlined the focus of their research projects. Therefore, by the time we met for workshop the participating teachers had a clear understanding of how the PLC would contribute to each of our studies. The planning workshop had the following aims. Firstly, it introduced the participating teachers to the construct of TSPCK and secondly, based on the findings of Phase I of the study that teachers focus on the algorithmic aspects of stoichiometry, it introduced ways in which to teach stoichiometry conceptually. Before the commencement of the workshop, the three participating teachers had completed the TSPCK and CK instruments in Phase I of this study. This served as the pre-test for measuring their TSPCK.

The format of the workshop, since the PLC was formed for the professional development of the participating teachers, was through their active participation (Borko, 2004). It therefore took into account what the participants already knew as experienced teachers (H.-J. Lee, 2005) and the focus was on discourse (Desimone, 2009). The workshop began by first

introducing the construct of TSPCK and the five components. The aim was to work through all five components, firstly by focusing on the first component, *learner prior knowledge*. However, the conversation moved to the component *what is difficult to teach*, with aspects of *curricular saliency,* such as identifying the mole as an important concept and sub-ordinate concepts related to the mole. The extract below provides a sense of how the workshop allowed the participating teachers to engage and discuss their ideas.

Stephen (line 1)**:** *As the starting point, you can then give your ideas. For example learner prior knowledge.*

Ellen (line 2)**:** *So you're asking what they know of the common misconceptions that learners would have with regard to stoichiometry. Just from your experience presumably, or if you've done some reading.*

Tendani (line 3)**:** *I think we would be looking at some big ideas on stoichiometry. Like the Mole concept is something that learners really find difficult to understand. Like we are starting from a mole …*
So the first thing that learners must understand is, what is a mole, in this document [CAPS curriculum document].

Stephen (line 9)**:** *Okay, and that is, for me, I think one of the big ideas about stoichiometry, is the understanding. And you can't say the mole, the mole is actually just the unit for the measurement amount of substance..*

Sipho (line 10)**:** *Ja, this is also related to the abstractness of the concept. It's very difficult to understand and even to imagine it as an educator. It's like a foreign concept. And the fact that it has to relate to, um, particles, whether ions, molecules, or atoms.*
And there are many ways of presenting it. Like as you are saying you can calculate it in terms of n is equal to number of particles divided by the Avogadro's number. Also in terms of the mass and molar mass. And also the molar gas volume. So there's many ways in which it is presented, it causes a lot of confusion.

Sizwe (line 12)**:** *I think that inasmuch as the mole is a very important construct in stoichiometry, there's a need also for prior understanding of where we are coming from when we talk of the mole, in terms of the periodic table, relative atomic mass, relative molecular mass, relative formula mass. And volume, mass on its own. As well as what has talked about the molar gas constant, Avogadro's constant. And I think all those are ideas that we need to gradually see how we pace them up when we teach stoichiometry.*

Stephen (line 13)**:** *Okay, so, and I mean, the mole has been identified as one of the main problems. But, what are some of the other misconceptions that you might have come across where learners struggle to do this stoichiometric calculation?*

Sizwe (line 14)**:** *Ja, the simple concepts like concentration on its own, which is usually number of moles over volume.*

Stephen (line 19)**:** *One of the misconceptions talked about in the literature is: if you ask, and I mean I've done this in class, is taken the same mass of potassium iodide, potassium bromide, potassium chloride, and then the same mass we've measured out and said, okay, which of these will have the same concentration?*

Stephen (line 20)**:** *And then the learners think, the same mass, and the same volume, they must have the same concentration. Because they're not taking into account that each of those salts … in that similar mass because of the different atoms that make them up have different...um … there's different amount of substance in each and therefore the concentration.*

What is clearly evident in this conversation is that the teachers, although they might not be aware of the common misconceptions from their experience, they have ideas of what makes the topic difficult to teach and the concepts that need to be taught. At the end of this discussion, each participant was provided with a list of common misconceptions related to stoichiometry (e.g. Dahsah & Coll, 2007; Potgieter *et al.*, 2005) that was prepared from a review of the literature during the design of the instrument (refer to Appendix 7).

According to Borko (2004), effective professional development for teachers is characterised by focusing on subject matter knowledge for teaching, student thinking and instructional practices. All of these characteristics are inherent in the construct of TSPCK since subject matter knowledge is transformed through the five components, and good subject matter knowledge influences teachers' PCK in a topic (Rollnick & Mavhunga, 2015). From the conversation above, the teachers' content knowledge is evident as they identify important concepts and subordinate concepts, evidence of *curricular saliency*. Student thinking is encapsulated in the components of *learner prior knowledge* and to some extent *what is difficult to teach*. The components *conceptual teaching strategies*, which includes *representations,* are essential aspects related to instructional practices. To integrate the characteristics of effective professional development with the construct of TSPCK, and to work towards focusing on instructional practices and learner tasks (Brodie, 2013; Brodie & Shalem, 2011), I presented various examples from my own classroom enactment. This was done to highlight teaching episodes that showed the integration of the TSPCK components.

These examples were presented as PaP-eRs (Loughran, Gunstone, Berry, Milroy, & Mulhall, 2000a) of what I had done in my own classroom. The examples included episodes related to introducing the term amount of substance, introducing Avogadro's constant as a way of determining the number of particles, dealing with the misconception that the same mass of different solutes did not have the same concentration. When describing each episode, I

mentioned the misconception, or aspect of learner prior knowledge the episode was dealing with, the concepts I was dealing with and the representations I used in the episode. For each episode, I had taken photographs of what I did in the classroom and presented these to the participants in a power point presentation during the workshop. For the participating teachers, understanding this aspect, identifying the TSPCK components, analysing how the components interacted, was key in examining their classroom enactment, of which Sandra reminded them after I had gone through the different examples.

> **Sandra** (line 162)**:** *It's how you use your knowledge about them [the TSPCK components] to bring and support an explanation [of the quality of TSPCK]. Okay. So if I were to analyse this, let's suppose we have a video[19] that starts like this, first of all I would have to analyse what components do I see? And do I think they interact? And in what way do they interact? It's when you can see evidence of that interaction then you can say, here I see demonstration of TSPCK. I call this a TSPCK episode.*

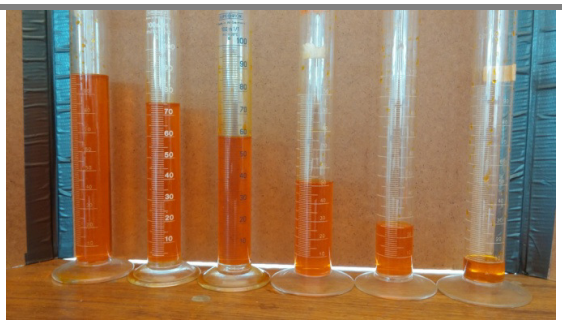
I have selected one of the examples of the episodes to describe here, related to the big idea about the concentration of solutions as the amount of substance per unit volume. The reason for this is that the other episodes related to the mole concept, formed the basis of the revision lesson we planned collaboratively, and the purpose of forming the PLC was to develop teachers' TSPCK in stoichiometry as a topic.

In this episode, I described how I dealt with the difficulty learners have understanding the significance of volume when understanding molar concentrations (Duncan & Johnstone, 1973), especially when solutions are diluted. This was the TSPCK component *learner prior knowledge*. I then described how I made up a molar solution of potassium dichromate, and then asked the learners if they thought the concentration would change if I poured different volumes of the solution into measuring cylinders. Then, as a demonstration, which is a representation at the macroscopic level, I poured the solution into the measuring cylinders so that the learners could compare the colours. By observation, the colour of the different solutions is the same.

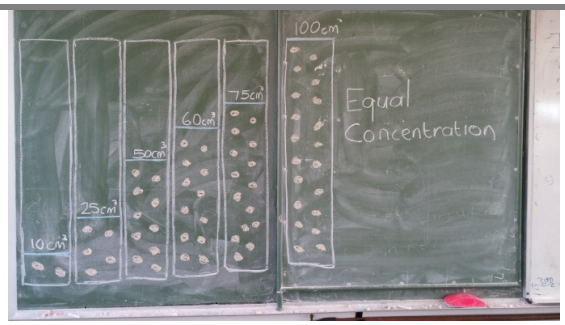
I then described how I drew particulate diagrams, which are sub-microscopic representations, of these solutions on the board and again asked learners if they felt the concentrations were the same. The photographs of these representations, which were used in describing the episode to the participating teachers, are shown in Figure 5.1. I then described how I

[19] Sandra is referring to the video lessons that would be recorded in each cycle of the Learning Study.

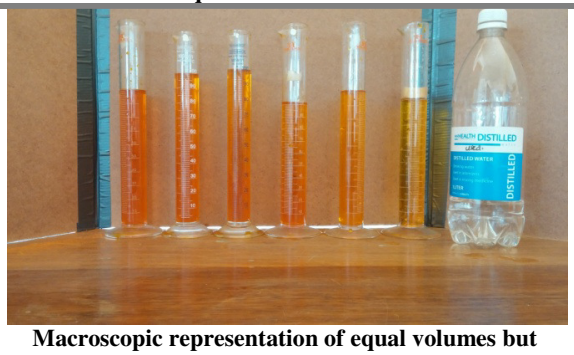
extended this activity by asking the students if they thought the concentrations would change or stay the same if I added water to the solutions in the measuring cylinders. I described then how I added water to the solutions, making the volume of the solutions the same and asking the students to make a qualitative observation based on the colour of the solutions to check their ideas about the concentration of the solutions. This was a representation at the macroscopic level. As with the first part of this episode, I drew up particulate diagrams of the solutions, a sub-microscopic representation (see Figure 5.1).



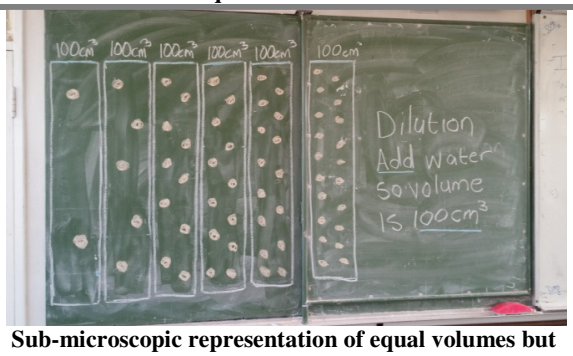
Macroscopic representation of different volumes but equal concentrations



Sub-microscopic representation of different volumes but equal concentrations



Macroscopic representation of equal volumes but different concentrations



Sub-microscopic representation of equal volumes but different concentrations

Figure 5.1: Macroscopic and sub microscopic representations of concentration used during the presentation describing a teaching episode

I explained to the participating teachers that once I had used *representations* at the macroscopic and sub-microscopic level, only then did I move on to symbolic representations in terms of using the formula to calculate the concentrations of the solutions. This example highlighted the use of using all three levels of representation in a conceptual teaching strategy, beginning with observable macroscopic observations, using particulate diagrams as a sub-microscopic representation, as seen in Figure 5.1, before using the volume measurements in calculations, which is a representation at the symbolic level.

At the end of the presentation, Maggie and Ellen explicitly linked the description of these episodes to the conceptual change approach. Maggie highlighted the importance of using an approach which brings in students' everyday experience to help explain abstract concepts in

science and challenging learners' intuitive ideas. She described how the activity can be enhanced by getting students to discuss their ideas to bring about cognitive dissonance and construct knowledge. Ellen reminded the participating teachers that they were introduced to this approach in one of the content courses they completed as part of the Masters' programme, and emphasised and linked it directly to the idea of 'good PCK', as shown in the extract below. This is the kind of exchange that motivated the inclusion of the supervisors as part of the PLC as science education experts (described in the previous section).

Maggie (line 170)**:** *It's everyday use of the concept. So that we are in the science classroom we have to take into account because the learners come across every day phenomena and in a classroom. In a science classroom it's about abstraction and it's about introducing those concepts which basically are about abstraction. And therefore learners who didn't intuitively maybe reason them out that way. So basically your approach was to try to challenge the intuitive notions which they bring into the classroom It's sort of something which is going to challenge those notions somehow, to cause a cognitive dissonance.*

Ellen (line 172)**:** *But I just want to refer you back to your teaching and learning course which you did last year, that what Maggie has been outlining is precisely what's referred to as a constructivist approach in teaching. So that the kind of standards that we're setting here [in the Professional Learning Community] for good PCK, are based really on what is accepted in science education as being good teaching.*

This subsection has described the planning workshop. It aimed at introducing the participating teachers to the construct of TSPCK, an essential conceptual artefact for our research community (Wenger, 2010). Through discourse, we were able to sift out what the participating teachers, from experience, perceived which aspects of *what is difficult to teach* in the topic, although the participants were not able to describe typical misconceptions, an important component of *learner prior knowledge*. During the planning workshop, with the aid of a power point presentation, various teaching episodes from my own practice were outlined. They were described specifically to outline the interaction of the different components of TSPCK since the collaboration aimed at examining classroom enactment using the construct of TSPCK, as the *specialised knowledge base* outlined in the working definition of a PLC provided in this chapter. In the next subsection, as our goal-directed collaborative action, a Learning Study, is described since this was the vehicle *to improve effectiveness as professionals and benefit student learning*.

5.3.2. Learning Study as the Professional Learning Community's Goal-directed Plan

Professional development activities of teachers are often inadequate, inappropriate and out of sync with research on how teachers learn (Kriek & Grayson, 2009). Professional development activities that build a teacher community by allowing teachers to work in groups and discuss issues, promote reflection and allow for some type of action research that allows them to focus on data from their own classroom that connects with other forms of knowledge, are considered exemplary strategies for professional development (Brodie, 2013; H.-J. Lee, 2005). The previous subsection described the workshop component of the first meeting of our PLC that introduced the teacher participants to TSPCK to connect their classroom enactment (Brodie, 2013; Kriek & Grayson, 2009). The workshop was important in developing the conceptual artefacts in order for the participating teachers, as members of the inquiry community, to develop meaning, or a way of talking about our practice as a community (Jaworski, 2008; Wenger, 1998b, 2010). This subsection describes Learning Study, our PLC's goal-directed action research, which is an inquiry cycle of plan, act and observe, reflect and analyse and use feedback to make improvements (Jaworski, 2008; H.-J. Lee, 2005).

The action research cycle of Learning Study, with features from design studies that attempt to report on arguments based on innovation and interventions in the classroom related to teaching and learning (Kelly, 2003), consists of five basic steps (Pang & Marton, 2003). Teachers work collaboratively in a systematic way during a Learning Study, often with researchers over an extended period of time to identify aspects of student learning of a topic in order to improve teaching (Kullberg, 2010; Nilsson, 2008). As illustrated in Figure 5.2, the process is a cycle of planning and evaluation, typically of one lesson, that pools the experiences of teachers to enhance student learning (Kullberg, 2010; Nilsson, 2014; Pang & Marton, 2003). The various steps, as outlined by Pang and Marton (2003), which Kullberg (2010) and Nilsson (2014) presented visually as a flow chart, is shown in Figure 5.2.

Step one in the flow chart (see Figure 5.2) is selecting the object of learning, usually a capability, value or concept that needs to be learnt, often something that students experience as problematic or difficult (Adamson & Walker, 2011; Nilsson, 2014; Pang & Marton, 2003). In this case, the focus is on a big idea in stoichiometry, therefore each big idea can be deemed

an object of learning. Pang and Marton (2003) stress that the initial characterisation of the object of learning must be grounded in theory, and the construct of TSPCK is grounded in the idea of the transformation of the teachers' content knowledge through the five components to help learners understand the concept (Mavhunga, 2012).

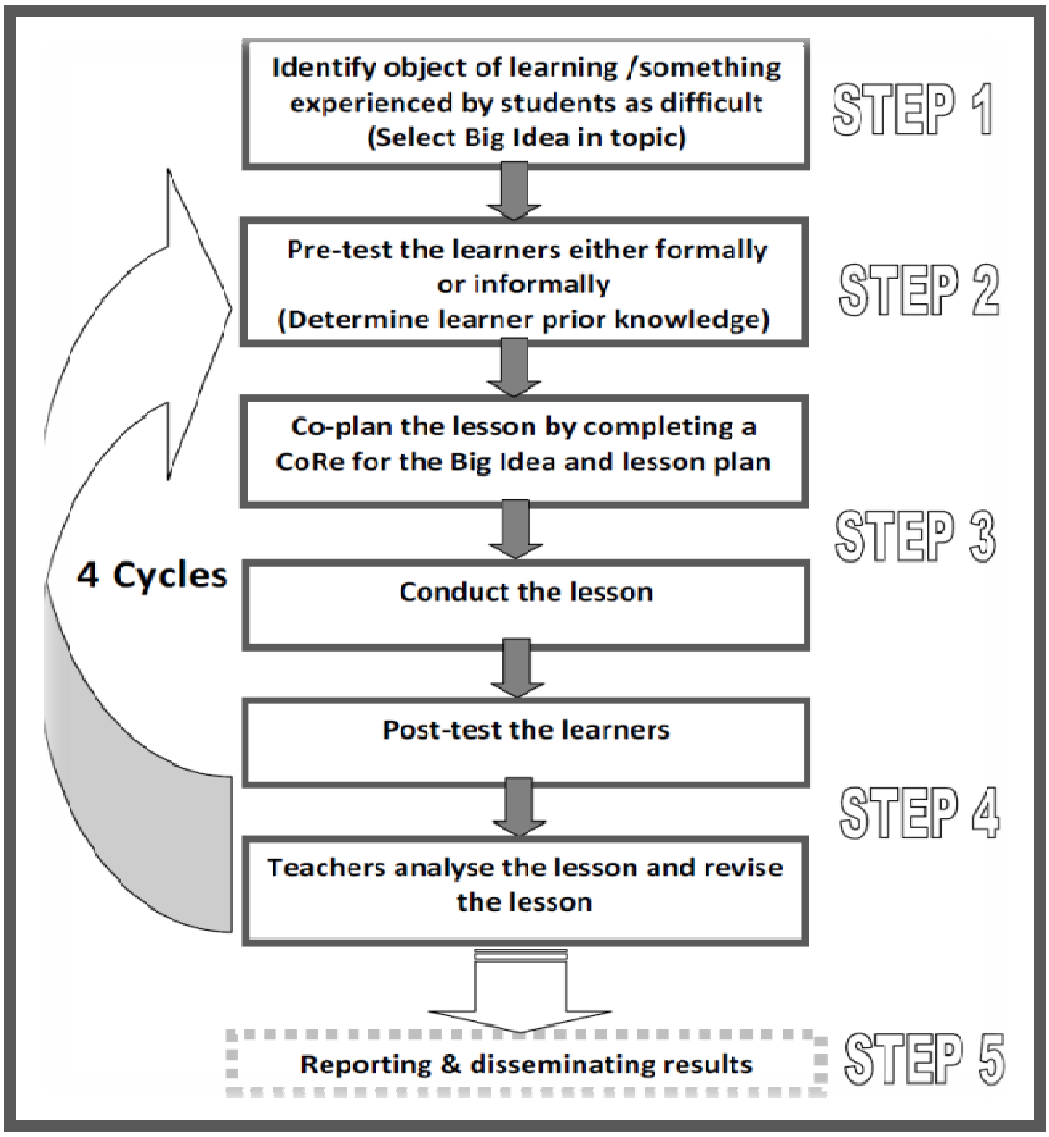


Figure 5.2: Steps in a Learning Study using a CoRe as a planning tool

The second step, is to determine student pre-conceptions by analysis of students' conceptions - usually a pre-lesson test or informally by scanning through questioning (Kullberg, 2010; Pang & Marton, 2003). In this case, the diagnostic reports from the Basic Department of Education who reported on Grade twelve's lack of understanding of stoichiometry concepts, evidenced by their inability to solve stoichiometric problems (Department of Basic Education, 2013, 2014) served to ascertain that, in general, the problem was widespread and served as the rationale for this study. In addition to this, a pre-test was also administered to

students but after the first lesson in the cycle was planned to determine the preconceptions of the specific students being taught during each cycle.

The third step is the planning and implementation of the lesson, which, in Figure 5.2, is separated out as two sub-steps, co-planning and conducting the lesson (Kullberg, 2010; Nilsson, 2014).The planning was collaborative, with the team of the PLC to complete a CoRe. The CoRe was a key tool in helping teachers identify critical aspects of the big idea for student learning (Nilsson, 2008)' The prompts in the CoRe help teachers focus on important aspects to consider when teaching a topic such as key content ideas, student preconceptions and ways of framing ideas to support student learning (Loughran, Gunstone, Berry, Milroy, & Mulhall, 2000b; Loughran, Mulhall, & Berry, 2008). The lesson was then implemented and in my role as participant-researcher, I taught the first cycle as a pilot lesson that was video recorded. Step four involved evaluating and revising the lesson and also consisted of two sub-stages (see Figure 5.2), which included giving the students a post-test to understand how students' understanding of the object of learning and its critical features had changed (Nilsson, 2014; Pang & Marton, 2003). The second sub-stage was to collaboratively analyse the teaching of the lesson. Each participant had watched it to share their experiences of the lesson, focusing on teacher instruction, in order to revise the lesson based on the experience of delivering the lesson (Adamson & Walker, 2011; Nilsson, 2014).

In the next cycle, the revised lesson on the mole concept was taught by one of the participating teachers, Sipho, and the same procedure was followed with changes being integrated into the third cycle. This time, Tendani was the teacher, with Sizwe teaching the final cycle in this iterative process (Adamson & Walker, 2011; Nilsson, 2014). The final step is to report on and disseminate the aims and results of the Learning Study to other practitioners and researchers in the field of chemistry education (Pang & Marton, 2003). In this case, since the focus of this study is the development of teachers' TSPCK, through participation in a Learning Study, this is done by presenting the final exemplar lesson in Appendix 16.

Identifying the Object of Learning

During the planning meeting, the participating teachers were presented with a summary of the outcome of the work done, in defining the content and identifying the big ideas for teaching stoichiometry for the design of the instruments (refer to Appendix 5 and Appendix 6). The

use of a big idea as an object of learning was justified based on the work of Pang and Marton (2005) who used Learning Study to develop student understanding that market prices in economics are linked to supply and demand, a fundamental concept in the subject. Clearly, fundamental concepts, or big ideas, can therefore be considered objects of learning. The big idea related to the mole concept, central to understanding stoichiometry and the quantitative aspects of chemistry (Kolb, 1978), was selected due to the difficulties students have in understanding this concept (Dierks, 1981; Gulacar, Overton, & Bowman, 2013; Lazonby *et al.*, 1982).

Another important aspect to consider when selecting the object of learning is to consider the reason for learning the concept. Ling (2012) expands on this aspect and includes reasons such as the capabilities you want students to develop, how it relates to topics that students will learn in the future and the value of learning the concept and whether learning this concept has relevance to students' everyday lives and gives them a better understanding of the world they live in. These reasons are exemplified in the prompts A1 and A2 of the adapted CoRe, shown in Figure 5.3, which was the tool used to help plan the lesson.

Big Ideas
A. Curricular Saliency
A1. What do you intend students to learn about this idea? *(original)*
A2. Why is it important for students to know this? *(original)*
A3. What concepts need to be taught before teaching this idea? *(adapted – added)*
A4. What else you might know about this idea (that you don't intend students to know yet) *(original)*
B. What makes topic easy or difficult to understand
B1. What do you consider easy or difficult about teaching this idea? (*Adapted from original: Difficulties/Limitations connected with teaching this idea)*
C. Learner Prior Knowledge
C1. What are typical students' misconceptions when teaching this idea? *(Adapted from original: Knowledge about students' thinking that influences your teaching of this idea)*
D. Representations
D1. What Representations would you use in your teaching strategy? *(adapted – added)*
E. Conceptual Teaching Strategies
E1. What effective teaching strategies would you use to teach this big idea? (adapted)
E2. What questions would you consider important to ask in your teaching strategy? (*E1 and E2 adapted from original: Teaching procedures)*
F. What ways would you use to assess students' understanding? *(Adapted from original: Specific ways to ascertain understanding)*
G. What aspects of teaching and planning this big idea would you like to reflect on?

Figure 5.3: The adapted CoRe used to plan the lesson of the Learning Study

Using the Adapted CoRe to Plan the Lesson

The adapted CoRe (see Figure 5.3) is based on format introduced by Loughran *et al.* (2000b) in workshops, to get teachers to think about and share with others their knowledge about teaching a particular topic. The adapted CoRe (see Figure 5.3) was specifically modified to reflect the five components of TSPCK explicitly (Mavhunga, 2016). Below is an example of how the discussions in the planning meeting contribute to the development of the adapted CoRe.

One of the prompts in the adapted CoRe and one of the components of TSPCK is *what makes the topic easy or difficult to understand* (labelled as B in Figure 5.3). This knowledge component is linked to identifying concepts, including important gate-keeping concepts that are difficult to learn (Mavhunga, 2012). One of the first aspects brought up in the conversation was the abstractness of the concepts of stoichiometry reported in the literature (Georgiadou & Tsaparlis, 2000). The abstract nature of the mole concept was alluded to in terms of the magnitude of the size of Avogadro's constant being the number of particles in one mole was mentioned by Tendani even before the team got to this prompt in the adapted CoRe.

Tendani (Line 291)**:**	*I don't know whether the idea of working with this large number of particles is important, since you are talking about that as a number.*
Ellen (Line 292)**:**	*But that isn't the reason why, it's a correct idea, but I don't think it falls into why. It might fall into what are the difficulties associated with teaching this concept.*

Later during the conversation, the abstract nature of the mole concept was further elucidated by discussing the aspects that make the mole concept abstract, such as the magnitude of Avogadro's constant, that it represents a large number of particles that cannot be seen and the idea that it is used as a counting unit and represents a number. This is one of the conceptions of the mole discussed by Strömdahl *et al.* (1994) and, as the facilitator fulfilling my role as the facilitator of knowledge (Fulton & Britton, 2011), I reminded the team that this was an analogy, as is evident in the extract of the conversation below. Other aspects, also reported on in the literature as difficulties related to teaching stoichiometry that were brought up in this conversation included mathematical reasoning (Evans *et al.*, 2008; Yaron *et al.*, 2004) and the use of language in different mathematical relationships for calculating amount of substance (Furio *et al.*, 2000; Packer, 1988).

Ellen (Line 313)**:** *So what is easy or difficult in teaching the big idea? Everyone?*

Sipho (Line 314)**:** *The abstractness of the concept.*

Ellen (Line 315)**:** *Okay, now we must be careful because if we say something is abstract we have to say why it's abstract.*

Sandra (Line 316)**:** *What makes it abstract?*

Ellen (Line 317)**:** *So yes, it's abstract but what is it about the mole that…and there we get to Tendani's point, you see.*

Stephen (Line 316)**:** *That, ja, that's a large number.*

Ellen (Line 319)**:** *A large number of things we can't see.*

Sandra (Line 320)**:** *That we talk as, it's as if you're going from multiple to one. We talk about them as in units.*

Ellen (Line 321)**:** *It's a single entity that counts a large number of units. That might be one of the difficulties. What other difficulties are there related to the topic?*

Sandra (Line 322)**:** *That as a counting unit it has no units.*

Ellen (Line 323)**:** *Or the idea that it is both a unit and a number. Or whether it's a unit. I mean, that we've knocked out ourselves. Yes, do we introduce it as a number? Do we introduce it as a unit? It can't be both a unit and a number at the same time.*

Stephen (Line 324)**:** *Or if we do that, it's an SI unit but we use it as a counting unit because it's easier to understand. And that that way we're keeping the, in a sense, the science, yes we're acknowledging it's the SI unit for amount of substance. So using the language amount of substance is important to also help overcome the language issue about how learners use amount. So use amount of substance. Say I'm going to be calculating the amount of substance, but we're using the mole, its unit as a counting unit because it's easier for us to work with. There's nothing wrong with letting learners know I'm using this as an analogy and it is an analogy that makes it easier to understand something that's difficult.*

Ellen (Line 325)**:** *And the slippage of language as well* (referring to the use of number of moles instead of amount of substance).

Tendani (Line 326)**:** *I also think what might be difficult here involves the calculations of this number of moles. The mathematical part of it. Calculations involving moles.*

Ellen (Line 327)**:** *So yes, calculating, and even saying the number of moles is not correct. Are there any other difficulties, key ones that we've left out?*

Sandra (Line 328)**:** *Do you think the idea that it can be calculated from different perspectives is an issue?*

Ellen (Line 329)**:** *You mean like you can calculate it from volume and...* [mass]?

During this exchange, the ideas for this prompt of the CoRe were recorded on a sheet of paper and later typed up to produce the CoRe as shown in Figure 5.4.

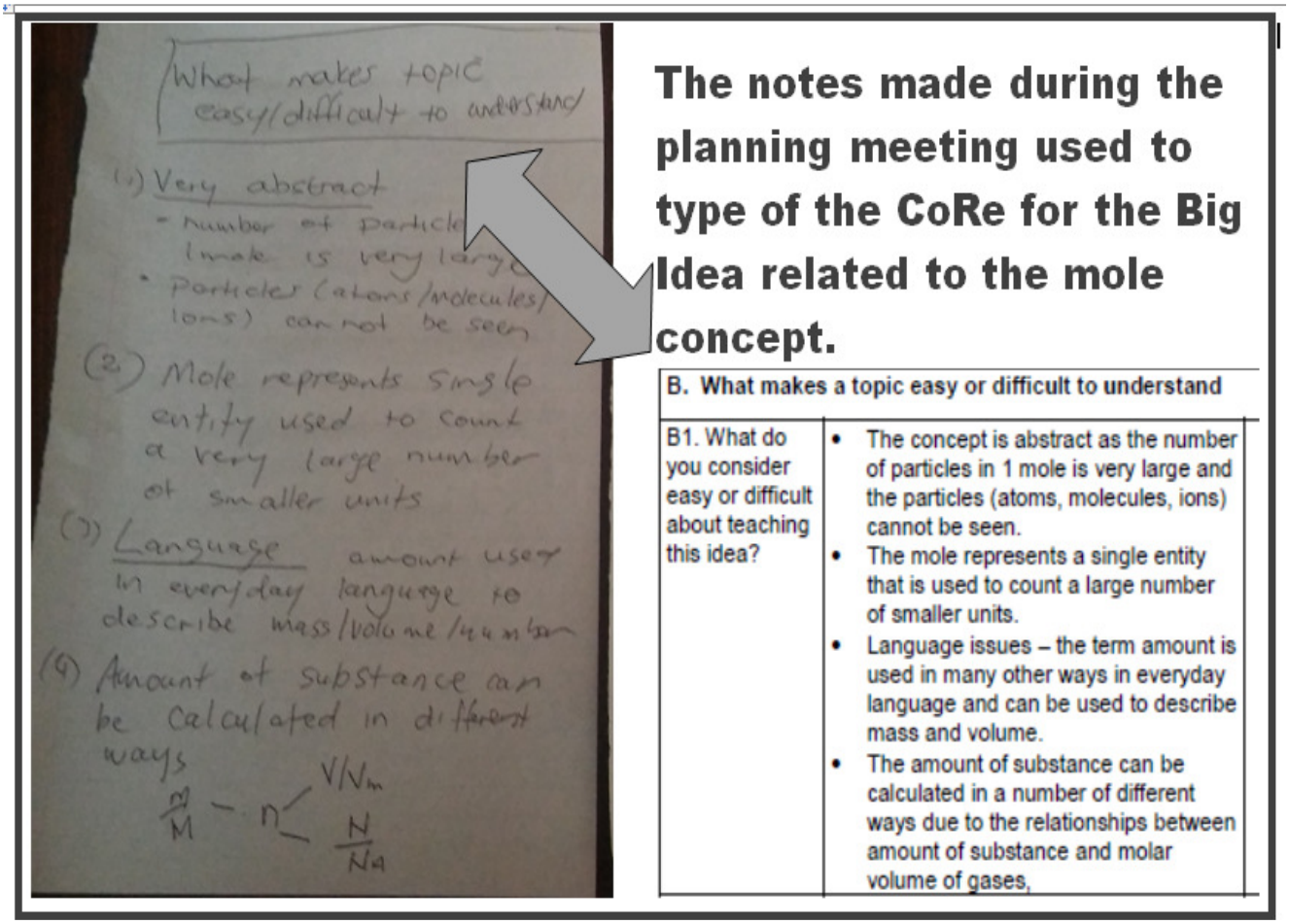


Figure 5.4: From the planning meeting the written out aspects of what is difficult to teach are captured in the adapted CoRe

The process shown above in Figure 5.4 was followed for the prompts C1, (*Learner prior knowledge*) and D1 (*Representations*) of the adapted CoRe, with the team providing their input which was captured on separate sheets of paper and then typed up to produce the CoRe for the Big Idea related to the mole concept. For the prompts related to *Conceptual teaching strategies* (E1 and E2), Sandra spent some time explaining what was meant by a *conceptual teaching strategy*. She explicitly contrasted it to general pedagogy, using various examples drawn from the presentation of my teaching strategies used when introducing the participating teachers to the construct of TSPCK. She explained that it was a step-by-step description of what the teacher would do to transform the content for students to understand. She highlighted that a *conceptual teaching strategy* takes into consideration *learners' prior knowledge* such as misconceptions, or *what makes it difficult to teach*, and integrates the representations into a step-by-step explanation of an activity that develops student

understanding. Later on, she explained that the questions needed to support the strategy being described (prompt E2 in Figure 5.4). These ideas were all incorporated into the CoRe (see Appendix 16) for the lesson, which I, as facilitator, compiled from the notes of our discussions. The CoRe was distributed electronically to the team in order to move to the final stage of planning and developing a lesson plan, which was discussed at the planning meeting (refer to Table 5.1) a week later.

From Adapted CoRe to a Lesson Plan

From the conversations during the planning workshop, in which the participating teachers were introduced to the construct of TSPCK and the adapted CoRe, I captured the team's discussions by completing the CoRe. Four teaching activities were discussed, each activity representing a conceptual teaching strategy to deal with the misconceptions and difficulties associated with teaching the mole concept. For a detailed discussion on the lesson refer to Appendix 16. The discussion was used to refine each of the conceptual teaching strategies discussed, including the types of representations used. The sequence of the conceptual teaching strategies were formalised into a formal lesson plan. The purpose of the lesson plan was to formalise the lesson and include teacher and student activities, the resources needed for the different activities and a suggested time frame for each activity. An extract of the lesson plan, which is included in Appendix 16, is shown in Figure 5.5. The extract from the lesson plan is for the introduction to the second activity for which the dozen coins macroscopic analogy was used as a representation.

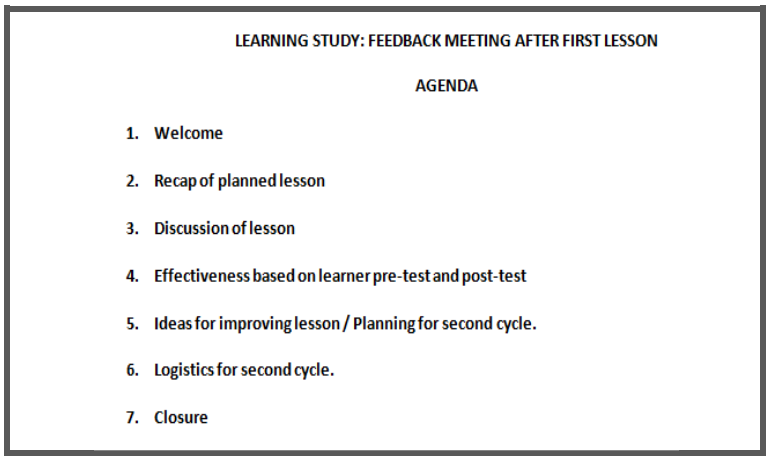
Duration	**Teacher Activity**	**Student Activity**
Activity 2 The analogy of the mole as a counting unit such as a dozen **20 minutes**	1. Introduce the next activity as a way for learner to understand how the amount of substance as a quantity can be used to help count the number of particles. Introduce 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.	Learners respond – a dozen represents twelve, two dozen represent twenty four, half dozen represents six.
Resources	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.	

Figure 5.5: Extract from the lesson plan drawn up from the discussions of the conceptual teaching strategies indicating teacher activities, learning activities and resources

The Four Cycles of the Learning Study

The collaboratively planned lesson was piloted with a group of my students at Mansfield High School[20] during the July school holiday with twelve Grade eleven students. I taught the pilot lesson in order to help create an open and trusting environment necessary for collaborative, generative inquiry into classroom enactment, in order to relate to the participants as a teacher sharing practice since South African teachers are not encouraged to share educational practices (Botha, 2012; Toma, 2000; Yorks, 2005). Before the lesson, the students completed a pre-test and completed a post-test after the lesson. The lesson was video-recorded in order for the participating teachers to evaluate it, so that it could be refined and improved in discussion meetings (Verhoef, Coenders, Pieters, van Smaalen, & Tall, 2015).

The first meeting after teaching the planned lesson on the mole, happened two weeks after the lesson was taught. The video-taped lesson was distributed one week before the meeting to analyse the lesson for the team members prior to the meeting, with the detailed lesson plan (included in Appendix 16). Participants were asked to review the lesson before the scheduled meeting. Before this meeting, the student pre-tests and post-tests were scored since in a Learning Study, the results are used to ascertain how well the students developed the capability, in this case a conceptual understanding of the mole concept (Pang & Marton, 2003). An agenda (see Figure 5.6) was drawn up that included recapping the purpose of the lesson, a discussion of aspects of the lesson and a review of the performance of the learners in the pre-lesson and post-lesson diagnostic tests.


LEARNING STUDY: FEEDBACK MEETING AFTER FIRST LESSON

AGENDA

1. Welcome
2. Recap of planned lesson
3. Discussion of lesson
4. Effectiveness based on learner pre-test and post-test
5. Ideas for improving lesson / Planning for second cycle.
6. Logistics for second cycle.
7. Closure

Figure 5.6: The agenda for the discussion meeting held for the piloting of the lesson on the mole

[20] Not the real name of the school. This is an invented name to ensure anonymity of the students.

In addition, an outline of the lesson was drawn up to aid referral to aspects of the lesson during discussions. Based on the discussion, aspects of the lesson were revised and improvements recommended, which are discussed in the Appendix 16 related to the evolution of the lesson. Finally, the logistics for the second cycle, as per the agenda shown in Figure 5.6 were discussed.

The second cycle of implementing the planned lesson was conducted by Sipho. Before he taught the lesson, Sipho and I met during the week prior to the lesson. During the meeting, we worked together firstly, to implement the changes as discussed in the discussion meeting and change the lesson plan accordingly. Secondly, we discussed the use of the resources for the lesson to familiarise Sipho with them. Sipho taught the lesson on the Saturday to twenty Grade 11 learners from Mangosuthu Secondary School[21] in the West Rand where he worked. Before the lesson, I conducted a pre-lesson interview related to the context of his school, his understanding of the purpose of the lesson and what misconceptions and difficulties he had encountered when teaching stoichiometry (see interview protocol in Appendix 2). The lesson was planned for two hours, although it was completed in just over three hours. In order to later analyse the lesson in a discussion meeting, the lesson was video-recorded (Pang & Marton, 2003). Before and after the lesson, the learners completed a pre-test and post-test to ascertain how well they developed a conceptual understanding of the mole concept. The video of the lesson was distributed to the team for the next post-lesson discussion meeting. The second discussion meeting followed a similar format to the first one (see the agenda in Figure 5.6), although the effectiveness of the lesson based on the pre-test and post-test scores was discussed before discussing the lesson. During the discussion meeting, the focus was on streamlining the lesson to reduce the time. The logistics for the next cycle were also discussed.

The third cycle of the Learning Study was conducted by Tendani. As with the previous cycle, Tendani and I met to implement the changes to the lesson plan and discuss the use of the resources. Tendani conducted the lesson with twenty volunteers from his Grade 11 students at Jukskei River Secondary[22] in Johannesburg which was video recorded. Before he taught the lesson, I also conducted the pre-lesson interview with him. The students completed a pre-

[21] Not the real name of the school. This is an invented name to ensure anonymity of the students and the teacher.
[22] Not the real name of the school. This is an invented name to ensure anonymity of the students and the teacher.

lesson and post-lesson test, which were assessed and the results were discussed during the third discussion meeting. During this meeting, we first discussed the logistics for the last cycle to ensure the last lesson was conducted before the end of the term. The team then discussed the lesson and ways to improve it, which included an overhaul in terms of the sequencing of activities in order to move from a more concrete example of the mole as a counting unit. These changes are outlined in Appendix 16.

The final cycle was taught by Sizwe after we had met to implement the changes to the lesson plan. Sizwe taught the lesson to nineteen students at his school, Rolihlahla Secondary School[23] in the West Rand. As with the previous cycles, the lesson was video recorded, I conducted a pre-lesson interview with Sizwe and the students were pre-tested and post-tested to determine the effectiveness of the lesson. The final discussion meeting was held to discuss the results of the pre-test and post-test and the lesson. During the final discussion meeting, some time was also spent on reflecting on the lesson. The consensus from the team, despite this lesson being planned as a revision lesson, was that the number of concepts packed into the mole as a big idea required more time than a single lesson. There was therefore not enough time for the repetition of the important aspects of the big idea. For more details on the lesson and the resources used refer to Appendix 16.

To provide some sense of the lesson a collage of pictures from the four cycles are shown in Figure 5.7. As is evident from these pictures the lesson incorporated hands-on activities and practical work, where students had to measure out spoonfuls of different substances. The lesson also included working with the analogy of a dozen coins, to move from a more concrete example of a counting unit, before introducing the mole was a way to count elementary particles. Students were actively involved in doing stoichiometric calculations and sharing their answers. When dealing with molar volume, the teachers used an overhead projector and transparency that included three levels of representation. The sequence of the teaching activities changed through the four cycles, with activities either modified or removed from the lesson plan based on student performance in the diagnostic tests. The lesson plan for the first cycle is included in Appendix 16, which outlines how the lesson changed during the four cycles of the Learning study.

[23] Not the real name of the school. This is an invented name to ensure anonymity of the students and the teacher.

Figure 5.7: A collage of pictures from the four cycles of the lesson on the mole

Post Learning Study Activities

After we had completed the last discussion meeting in the cycle, each of the participating teachers completed the TSPCK instrument again as a post-test. These were scored using the TSPCK rubric independently with one of members of the PLC team as outlined in Chapter 3. The pre-test and post-test instruments were used to determine the teachers' TSPCK development through participation in a Learning Study. The analysis of this data is described in Chapter 6. Each of the participating teachers then worked independently on their own research projects, analysing their practice from the video-recorded lessons. I helped facilitate their thinking by providing them with a template to record what components of TSPCK were evident in their lessons, what worked and how they would improve aspects of the lesson. A sample of the participants' own analysis of their lessons is included in Appendix 20.

After a six-month hiatus, during which they had analysed their own lessons and had either submitted or were close to submitting their research reports, I contacted them to set up a schedule for my data collection. This included meeting at their schools to conduct a video stimulated recall interview (SRI). SRIs are a research technique where the teachers viewed video sequences of their teaching and were asked to reflect on their decision-making processes in the video segment (Nguyen *et al.*, 2013). The interview protocol for SRIs is included in Appendix 2. Finally, after I had completed SRIs with all three of the participating teachers, I scheduled an exit discussion as an informal, semi-structured information gathering session (Lefkowitz & Katz, 1969). Such exit interviews or discussions are useful as they often provide valid concerns not previously expressed or uncover particular misconceptions related to the intervention (Doll & Jacobs, 1988). Unfortunately, due to personal reasons, Tendani was unable to attend and so only Sipho and Sizwe participated. During this discussion, we focused on what they had learnt from participating in a Learning Study. The data collected from the SRI and exit discussion were used for my study when examining classroom enactment, which is discussed in Chapter 7.

5.4. Summary

This chapter has provided a detailed account of the Learning Study as a collaborative professional development activity. Due to the collaborative nature of a Learning Study, an account of the formation of the Professional Learning Community has been described, including a working definition of a PLC. A detailed account of the intervention, including the

introductory workshop, has been outlined. An account of the planning using TSPCK as the knowledge base around which the discussions related to the planning and evaluation of the lesson by the PLC, has been provided. The chapter has included extracts of the discussions to provide a sense of the participation and interactions that are investigated in Chapter 6 to account for the TSPCK development of the teachers. This intervention was therefore the vehicle in which to investigate the development of the participating teachers' TSPCK. The lessons planned and taught by the teachers, provided the data to investigate how the collective TSPCK evident in the PLC were manifest by the participants in classroom enactment when teaching the lesson. Chapter 7 reports on the teachers' enacted TSPCK in the classroom.

CHAPTER SIX

The Impact of the Learning Study on the Quality of Teachers' Measured TSPCK

This chapter aims at providing an overview of the impact of the Learning Study on the quality of the three participating teachers' TSPCK development. This chapter therefore informs the second sub-question of the research question. In order to do so, firstly the results of a second Rasch analysis, that includes the post-test scores of the three teachers, are discussed to highlight the impact of the Learning Study on their placement in the sample of teachers. Secondly, a narrative is provided from the qualitative analysis of the data to account for the performance of each of the teachers in the different components of the TSPCK Instrument, after participating in the various activities of the Professional Learning Community. This is described firstly, in terms of the participation of each of the teachers in the discussions with the expert members in the Professional Learning Community. The planning meeting and each of the four discussion meetings after each lesson cycle in the Learning Study were transcribed and coded in terms of 'talk units'. Four levels of coding were applied to the transcripts. The first level of coding was aimed at identifying which member of team was participating in the discussions. The second level of coding aimed at distinguishing talk units related to the professional knowledge being used to examine practice from talk-related to general aspects of logistics and research. The third level of coding applied the model of Teacher Professional Knowledge and Skills as an analytical framework to distinguish between topic-specific PCK and other professional knowledge bases and classroom practice or enactment. The final level of coding looked specifically at TSPCK talk units and these were coded in terms of the TSPCK component under discussion. Secondly, each teacher's change in score is examined qualitatively and explained in terms of aspects of the discussions in the meetings and described in vignettes. The vignettes draw on evidence from the meetings, the instruments, including a beliefs questionnaire, and the interviews held with the teachers before and after they taught their lesson.

6.1. Introduction

A key focus of this study was to investigate the development of the participants' TSPCK in stoichiometry through their participation in a Learning Study. The three participant teachers all completed the TSPCK Instrument in stoichiometry. This was done during the first phase of this study, the design and validation of the instrument which is reported on in Chapter 4. The instrument was initially administered to experienced practising science teachers to determine the quality of practising teachers' TSPCK in stoichiometry (see Chapter 4). The measurement of the three Learning Study teachers' TSPCK during the first phase of the study served as a pre-test before convening the Professional Learning Community. The post-testing was done after all four cycles of the Learning Study were completed, including the planning sessions and the discussion meetings after each participant had taught the lesson. Since only three teachers participated in the Learning Study, the analysis that follows firstly looks at Rasch measures of these teachers' scores before and after the Learning Study to investigate changes in their TSPCK, in combination with their peers who responded to the questionnaire earlier in Phase I by stacking their data (Wright, 1996). Secondly, emerging patterns in the quantitative scores for the five components of TSPCK were determined through the qualitative analysis of their responses. This qualitative analysis was used to compile vignettes to highlight and describe the changes in scores, which are then analysed in terms of participation in the meetings to provide insights into the changes in scores.

6.2. Teachers' Change in Score on the TSPCK Instrument

The pre-test scores were scored during the validation phase of the study using the TSPCK rubric (refer to Chapter 4 for more detail on the scoring process and rubric). The post-test instruments were scored in independently with one of the members of the PLC using the same rubric and scores were compared and differences discussed until consensus was reached. The final scores for each component of TSPCK from the participating teachers pre-test and post-test are recorded in Table 6.1 on the next page.

Table 6.1: Scores from the TSPCK Instruments of the participants involved in the Learning Study

Component	LPK		CSA		WDT		REP		CTS	
Test	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Sipho	3	4	3	3	3	3	2	4	2	3
Tendani	3	4	2	3	2	4	2	3	2	2
Sizwe	3	4	1	3	2	3	2	4	2	3

As is evident in Table 6.1, the scores for most of the components of TSPCK have shown improvement. In all three cases, learner prior knowledge (LPK) increased from a score of 3 to a score of 4. Tendani and Sizwe moved to developing TSPCK from basic and limited TSPCK respectively on the item relating to curricular saliency (CSA). All three participants improved in the item relating to representations (REP), with Tendani improving the least but Sipho and Sizwe scored exemplary TSPCK in this component. Tendani and Sizwe also improved in the item relating to what is difficult to teach (WDT). Tendani was the only participant not to improve his score in the item on conceptual teaching strategies (CTS).

Due to the small sample size, and since some components showed no change in score for the three participating teachers, it was not possible to determine if these changes were significantly different. However, since the designed instrument is a valid instrument to measure TSPCK in stoichiometry (see Chapter 4), Rasch measures were used to investigate these changes in score (Wright, 1996), which is described in the next section.

6.3. Comparison of Pre-Test and Post-Test Scores Using Rasch Measurements

The Rasch model is typically used to investigate changes in scores to evaluate the effectiveness of interventions and learning gains after an intervention through pre-testing and post-testing (e.g. Herrmann-Abell *et al.*, 2013; Pentecost & Barbera, 2013). This is done by 'racking' and 'stacking' where racking investigates the impact of an intervention on item difficulty and stacking investigates the impact of an intervention on a person's ability in the test (Wright, 1996). This conventional method for stacking and racking proved problematic for this study. Therefore a statistically justified unconventional approach was used to tackle this problem using the Rasch model to investigate the three teachers' improvement in scores. The dilemmas faced and the solutions, as well as the results of the process are described in this subsection.

6.3.1. Stacking of the Pre-test and Post-test Scores

Conventionally stacking and racking are used to measure changes between two time points, before an intervention and after an intervention, using the same test items (Wright, 1996). With stacking the responses to test items on different occasions, such as before and after an intervention are analysed as though the test was completed by different people and are placed vertically in the data set (Linacre, 2012; Wright, 1996). This is typically done by including the scores of the pre-test and post-test in one data file for Rasch analysis (Linacre, 2012) and then using the two ability measures per respondent to determine the change in scores (Herrmann-Abell *et al.*, 2013). In addition, the item difficulty is usually anchored by selecting preset logit values that are used as reference values to calibrate the Rasch scale for comparable results (Linacre, 2012). In this instance, the logit values for the easiest item, LPK and the most difficult item, CSA (see Appendix 8) were used as anchors. With racking, the persons completing the same instrument at two points in time is done, with the assumption the persons remain unchanged and that the items get easier because of an intervention (Wright, 1996). However, in this case, this was not possible since only three teachers completed the pre-test and post-test and the small data set cannot be run through a Rasch analysis.

For the same reason mentioned above, the stacking of the data was problematic. However, if the three teachers involved in the Learning Study were assumed to be different people as is the practice with stacking, then they were drawn from the same population as the teachers involved in the validation of the instrument described in Chapter 4. This sample population consisted of experienced physical science teachers teaching Grade 11 chemistry. Therefore including them in a second Rasch analysis would be similar to what was done in the validation of the instrument but with a slightly bigger sample size. Working under the presumption that the two sets of Rasch analyses would therefore represent two independent samples, then any differences in the person mean and item mean would not be statistically significantly different (Skoog *et al.*, 2004). Secondly, by anchoring the logit values for LPK and CSA from the first analysis, it would calibrate the scale for the second analysis, allowing for a direct comparison of the three teachers' pre-test and post-test scores (Pentecost & Barbera, 2013). Thirdly, based on the validation of the TSPCK Instrument, since the second analysis only included three 'different persons' (Linacre, 2012, p. 542), the rank order of item difficulty should remain unchanged, with CSA being the most difficult item. Lastly, if any

items or persons in the second analysis were misfiting, indicating unpredictable responses by the three teachers, this could be attributed to their participation in the Learning Study. Any response to an item that was above or below their person ability or vice versa could therefore provide evidence of what learning had occurred through their participation in the Learning Study. Figure 6.1 on the next page shows the bubble plots for the sample of thirty-one teachers and the 'larger sample' of thirty-four teachers, where the additional three teachers are the post-test scores in the TSPCK Instrument. The bubble plots show fit indices for the two samples.

As is evident in the bubble plots in Figure 6.1 for the two sets of analyses, with the original sample of thirty-one respondents, and the sample of thirty-four respondents, the item WDT and Tendani (labelled as 1L05) are not within the acceptable fit range of +2 and –2. The item WDT now has an outfit value of +5 in the second Rasch analysis. This indicates that some responses to this item are unexpected and above the person ability of low performing respondents (Bond & Fox, 2001; Boone *et al.*, 2014). The addition of the three teacher's post-test scores has shifted the fit of the WDT item substantially (see Figure 6.1). Initially the WDT item had a slight over fit, where high performing teachers did not do as well as expected in this item, of approximately –0.5. However, with the inclusion of the three teachers' post-test scores the outfit has now shifted and represents an under fit, where low performing teachers have done better than expected in this item. As is evident in Figure 6.1, respondent L05, Tendani's post-test score, has also flagged him as a misfiting person in the second analysis. He is literally off the scale as an outlier with an outfit value of over +8 which in a Rasch analysis indicates that his score distorts and degrades the measurement system (Boone *et al.*, 2014). Tendani therefore, based on his person ability has performed much better than expected in items such as the WDT item. This misfit of the item WDT is discussed later in this chapter, based on Tendani's results in the post-test. The bubbles for all three teachers' pre-test scores are also indicated on both sets of Rasch analysis. In the post-test Rasch analysis, the size of the bubbles for Tendani (L05), Sipho (L04) and Sizwe (L06) are larger. The size of the bubbles indicates the error in estimating their ability (Boone & Rogan, 2005). This has increased in the post-test analysis due to the variation in their responses, particularly CSA, the most difficult item and CTS. The qualitative analysis of their responses to account for the changes in scores is discussed later in this chapter.

Bubble plot to show fit

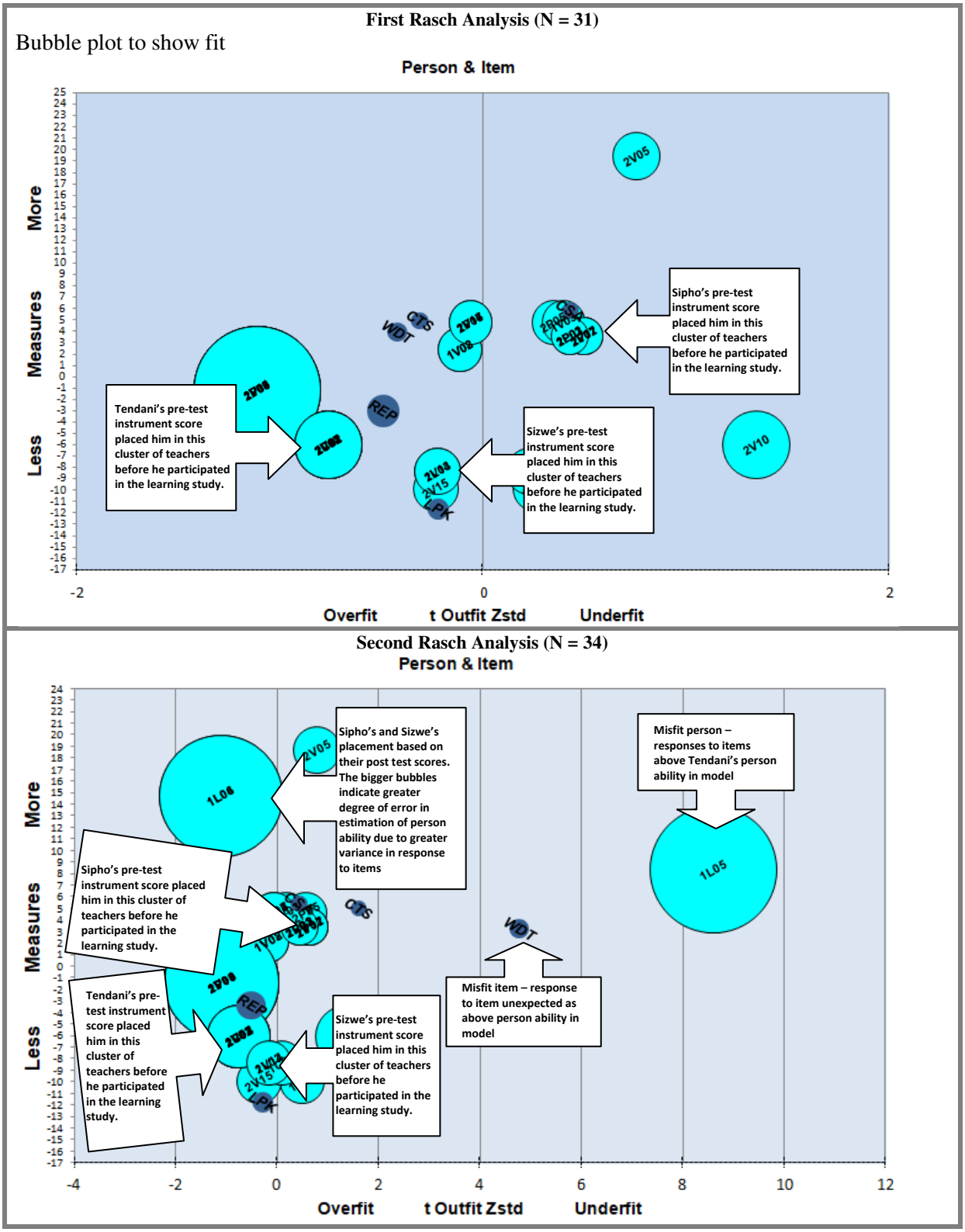


Figure 6.1: Rasch analysis data from original sample of teachers (N=31) and the stacked sample with post-test results from three teachers in the Learning Study

The glaring outfit outliers in the second Rasch analysis (see Figure 6.1) begs the question of whether the assumption made for stacking the data and treating the post-test scores as a 'larger sample' is acceptable. Do these outliers impact on the measurement in the second

Rasch Analysis? In order to answer this question, as has been mentioned the rank order of the items should remain unchanged and there should be no statistically significant difference in the item and persons means for both samples. Each of these assumptions is discussed below.

In terms of the item rank measure order, this is the same in both sets of analyses as can be seen in Figure 6.2. However, in the second analysis, there is a displacement in the rank order in the items of LPK, REP and CTS (see Figure 6.2). This displacement is due to the anchoring of item logit scores in the second analysis and scores are higher than expected in the model (Linacre, 2012). However, according to Linacre (2012) such random displacements that are less than 0.5 logits can be considered as having a negligible effect on what the instrument is measuring. The stacking of the post-test scores as the responses by 'three different people' in the second analysis, therefore did not have an effect on what the instrument is measuring, teachers' TSPCK in stoichiometry.

Item Ranking Order in First Rasch Analysis (N = 31)

Item STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASURE-A CORR.	PTMEASURE-A EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Item
2	64	31	5.82	.47	1.24	1.1	1.06	.4	.79	.70	71.0	78.5	CSA
5	68	31	4.93	.48	.86	-.7	.57	-.3	.69	.73	80.6	77.9	CTS
3	72	31	3.92	.54	.97	.0	.52	-.4	.73	.78	77.4	83.8	WDT
4	83	31	-3.02	.91	.71	-.2	.21	-.5	.89	.88	96.8	95.4	REP
1	101	31	-11.66	.59	.83	-.7	.36	-.2	.65	.64	87.1	84.9	LPK
MEAN	77.6	31.0	.00	.60	.92	-.1	.55	-.2			82.6	84.1	
S.D.	13.3	.0	6.61	.16	.18	.6	.29	.3			8.8	6.3	

Item ranking Order in Second Rasch Analysis (N = 34)

Item STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASURE-A CORR.	PTMEASURE-A EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	DISPLACE	Item
2	73	34	5.43	.48	1.26	1.1	1.00	.4	.81	.76	73.5	80.4	.00	CSA
5	76	34	4.95A	.47	1.09	.5	3.07	1.6	.71	.76	79.4	80.8	-.19	CTS
3	82	34	3.22	.56	1.43	1.3	9.90	4.8	.75	.80	76.5	87.1	.00	WDT
4	94	34	-3.39	.85	.63	-.5	.19	-.5	.92	.90	97.1	95.3	-.01	REP
1	113	34	-11.80A	.60	.88	-.4	.36	-.3	.73	.73	88.2	87.4	.29	LPK
MEAN	87.6	34.0	-.32	.59	1.06	.4	2.90	1.2			82.9	86.2		
S.D.	14.6	.0	6.55	.14	.28	.7	3.64	1.9			8.6	5.4		

Figure 6.2: Rasch analysis data from original sample of teachers (N=31) and the stacked sample (N=34) with post-test results showing item ranking order

The bubble plot for the second Rasch analysis (see Figure 6.1) shows that the bubbles for the three participating teachers' post-test scores are larger, indicating an increase in the model error in estimating their positions on the scale (Boone & Rogan, 2005). The misfiting item

and person could also impact on the reliability of the instrument, and the assumption that the two samples are representative of the population group could be invalid. To determine if this was the case, the item measure and person measure means for the two samples were analysed. Figure 6.3 and Figure 6.4 includes the summary statistics from both sets of Rasch analyses from which the person mean and item mean were examined.

First Rasch Analysis (N = 31)

Person Measure

SUMMARY OF 31 MEASURED Person

	TOTAL SCORE	COUNT	MEASURE	MODEL ERROR	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD
MEAN	12.5	5.0	-.74	1.71	.81	-.1	.55	-.2
S.D.	2.1	.0	6.29	.84	.97	.8	.59	.7
MAX.	18.0	5.0	19.43	3.50	5.31	2.1	2.84	1.4
MIN.	9.0	5.0	-9.84	1.05	.03	-1.0	.02	-1.1

REAL RMSE	2.06	TRUE SD	5.94	SEPARATION	2.88	Person RELIABILITY	.89
MODEL RMSE	1.90	TRUE SD	5.99	SEPARATION	3.15	Person RELIABILITY	.91
S.E. OF Person MEAN = 1.15							

Second Rasch Analysis (N = 34)

Person Measure

SUMMARY OF 34 MEASURED Person

	TOTAL SCORE	COUNT	MEASURE	MODEL ERROR	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD
MEAN	12.9	5.0	.25	1.86	1.07	.0	.82	.1
S.D.	2.3	.0	7.09	.92	1.81	1.2	1.70	1.6
MAX.	18.0	5.0	18.63	3.69	9.90	4.7	9.90	8.6
MIN.	9.0	5.0	-9.99	1.08	.03	-1.0	.02	-1.1

REAL RMSE	2.91	TRUE SD	6.47	SEPARATION	2.22	Person RELIABILITY	.83
MODEL RMSE	2.07	TRUE SD	6.78	SEPARATION	3.27	Person RELIABILITY	.91
S.E. OF Person MEAN = 1.23							

Figure 6.3: Rasch analysis data from original sample of teachers (N=31) and the stacked sample (N=34) showing Person measure summary statistics

First Rasch Analysis (N = 31)

Item Measure

SUMMARY OF 5 MEASURED Item

	TOTAL SCORE	COUNT	MEASURE	MODEL ERROR	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD
MEAN	77.6	31.0	.00	.60	.92	-.1	.55	-.2
S.D.	13.3	.0	6.61	.16	.18	.6	.29	.3
MAX.	101.0	31.0	5.82	.91	1.24	1.1	1.06	.4
MIN.	64.0	31.0	-11.66	.47	.71	-.7	.21	-.5

REAL RMSE .63 TRUE SD 6.58 SEPARATION 10.52 Item RELIABILITY .99
MODEL RMSE .62 TRUE SD 6.58 SEPARATION 10.67 Item RELIABILITY .99
S.E. OF Item MEAN = 3.31

Second Rasch Analysis (N = 34)

Item Measure

SUMMARY OF 5 MEASURED Item

	TOTAL SCORE	COUNT	MEASURE	MODEL ERROR	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD
MEAN	87.6	34.0	-.32	.59	1.06	.4	2.90	1.2
S.D.	14.6	.0	6.55	.14	.28	.7	3.64	1.9
MAX.	113.0	34.0	5.43	.85	1.43	1.3	9.90	4.8
MIN.	73.0	34.0	-11.80	.47	.63	-.5	.19	-.5

REAL RMSE .64 TRUE SD 6.52 SEPARATION 10.15 Item RELIABILITY .99
MODEL RMSE .61 TRUE SD 6.52 SEPARATION 10.74 Item RELIABILITY .99
S.E. OF Item MEAN = 3.28

Figure 6.4: Rasch analysis data from original sample of teachers (N=31) and the stacked sample (N=34) showing Item measure summary statistics

As is evident in Figure 6.3, the standard error of the person measure has increased by 0.08 logits whereas the standard error of item measure (Figure 6.4) has decreased slightly by 0.03 logits. The person measure mean (Figure 6.3) has also increased from – 0.74 logits to 0.25 logits indicating that for the larger sample, the items were slightly easier (see Figure 6.4). For the item measure mean, the mean has moved from 0 to –0.32 logits as shown in Figure 6.4. Since the CSA item remained the most difficult item, the slight shifts or, as in Sipho's case, no shift, account for the item mean being slightly negative and the instrument was slightly

more difficult for the larger sample (Bond & Fox, 2001). The person separation and item separation values in the second Rasch analysis are above 2.5 and 5 logits respectively, so the replicability of the instrument in measuring TSPCK of another sample is still good. The person reliability for the second Rasch analysis is down by 0.06 at 0.83, which is still above the acceptable value of 0.7. The item reliability remains unchanged. This indicates that the instrument, in the second analysis is still reliable as a measure of teachers' TSPCK in stoichiometry. But are the differences in person and item means statistically significant?

The mean measure scores, with the standard error of the means (SE) were used to conduct a t-test using the *QuickCalcs t-test calculator* (GraphPad Software, 2014). The null hypothesis, considering the three teachers to be different people drawn from the same population, was that there should be no significant difference in the person means and the items means between the two groups. The results of the t-test for the person mean and the item mean provided P values of 0.61 and 0.95 respectively at a 95% confidence interval. The t-test results are included in Appendix 21. Therefore the null hypothesis, that there was no difference between the two samples was accepted and the Rasch analysis of the stacked second sample could be used to see gains in the three teachers' scores in the instrument. The gains in scores in the instrument are discussed in the subsection that follows.

6.3.2. Comparing Pre-test and Post-test Placement on Person-item Map

In the previous subsection, a statistical argument was provided for using the second Rasch analysis by stacking the three participating teachers' post-test scores into a second sample. The item measure for LPK and CSA from the first Rasch analysis, with the teachers' pre-test scores, were used as anchors in order to have the same logit scale to make a direct comparison with gains in the post-test (Pentecost & Barbera, 2013). The anchoring resulted in a slight displacement of the item measures (see Figure 6.1) but these were less than 0.5 logits and have a negligible impact on direct measurement (Linacre, 2012). The person-item map for the second Rasch analysis is shown in Figure 6.5. The person-item map, discussed in Appendix 8 is a map of person and item measures on the linear scale (Boone & Scantlebury, 2006), which, in this case, was anchored to ensure the same linear scale used in the validation of the instrument was used in investigating gains in the scores.

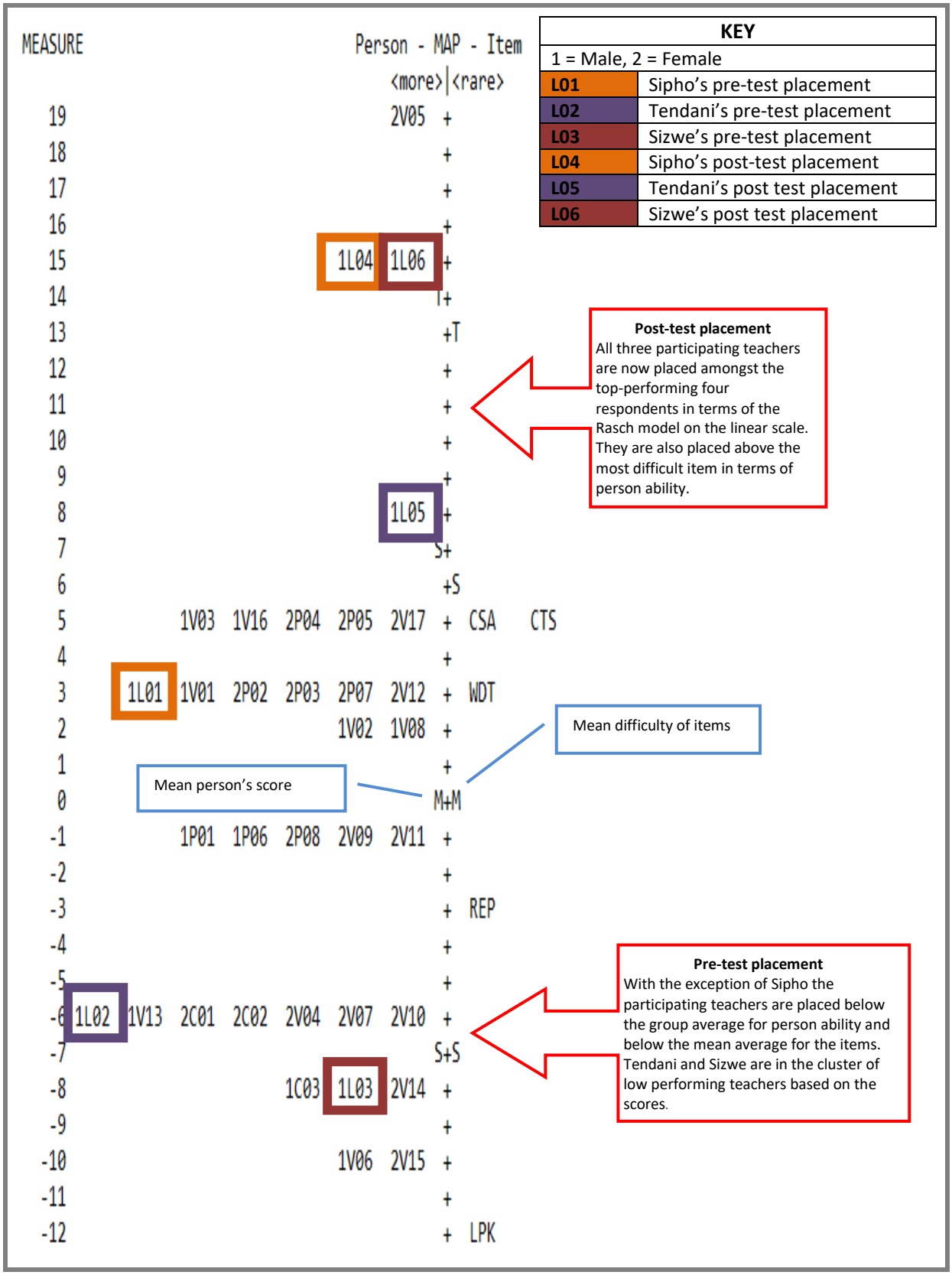


Figure 6.5: Person-item map with the post-test scores for the three teachers participating in the Learning Study included as new persons

As is evident in Figure 6.5, Sipho, Tendani and Sizwe are placed above both the person and item means (M on the linear scale) and, according to the Rasch model, based on their respective person ability measures, they have a greater likelihood of answering all the items correctly (Bond & Fox, 2001). The gains in their person ability are shown in Table 6.2. The person ability scores for each of the teachers are obtained from the person measure order table generated by *Winsteps*.

Table 6.2: Person measure values from Rasch analysis of the stacked data to show gains in person ability in terms of the Rasch model

Participant	Pre-test score (logits)	Post-test score (logits)	Change in person ability (logits)
Sipho (L01 & L04)*	+3.35	+ 14.70	11.35
Tendani (L02 & L05)*	– 6.10	+ 8.29	14.39
Sizwe (L03 & L06)*	– 8.41	+14.70	23.11
Mean score for sample (N=34)			**0.25 logits**
Median score for sample (N = 34)			**2.08 logits**

* These are the codes used for the teachers' pre-test scores and post-test scores

Based on the person measures of the three teachers for the pre-test and post-test, there has been a substantial gain on the logit scale which has a range of 28.5 logits. For both Tendani and Sizwe, who were ranked in the lower cluster of performing teachers based on their pre-test scores (see Figure 6.5), their change in scores indicate an increase in terms of person ability on the logit scale. All three teachers' change in score is also well above the median value for this sample. The median is the average of the two middle scores when placed in rank order for an even number of data sets (Bell, 2005), which for this sample is 2.08 logits. In other words, Sipho, Tendani and Sizwe are ranked in the top half of the sample who scored above the person mean of 0.25 logits in the stacked sample (see Figure 6.5). Therefore, based on their ranking on the logit scale, there has been an increase in their overall performance in the instrument. In addition, based on this change, a second cluster analysis was run and the results are discussed in the next subsection.

6.3.3. Change in Teaching Profiles Based on Cluster Analysis

Due to the changes in the three Learning Study teachers' scores in the post test TSPCK instrument the second cluster analysis indicated that they were now using teaching strategies that are conceptually adequate (see Section 4.6 of Chapter 4). The output data from the second cluster analysis is shown in Table 6.3 on the next page. This is an extract of the

cluster analysis to show the placement of the three teachers participating in the Learning Study. The complete cluster analysis is included in Appendix 21.

Table 6.3: Output data from cluster analysis showing groupings of teachers into 3 clusters

Respondent	Input Data for Cluster Analysis						Output Data	
	LPK	CSA	WDT	REP	CTS	Mole Conception	Allocated segment (N = 31)	Allocated segment (N = 34)
L01	3	3	3	3	2	4	1	1
L02	3	2	2	2	2	4	2	2
L03	3	1	2	2	2	4	2	2
L04	4	3	3	4	3	4	n/a	3
L05	4	3	4	3	2	4	n/a	3
L06	4	3	3	4	3	4	n/a	3

As is evident in Table 6.3 Sipho (L01) was initially placed in segment 1, which was described as algorithmically adequate. Tendani (L02) and Sizwe (L03) were placed in segment 2, which was described as algorithmically inadequate (refer to Chapter 4 and Appendix 15. This placement was based on their pre-test scores in the TSPCK instrument and CK instrument. Based on the post-test TSPCK scores all three teachers were allocated to segment 3, described as conceptually adequate in Chapter 4.

This section has provided statistical evidence from both Rasch analysis and cluster analysis that participation in a Learning Study improved the three teachers' TSPCK measure and resulted in movement from their respective teacher profiles. In the next section, their participation in the planning and discussion meetings will be unpacked, in order to account for the change in their ranking on the scale that measures teachers' TSPCK.

6.4. The Focus and Participation in the Professional Learning Community

According to Grossman, Wineburg, and Woolworth (2000), the rationale for a PLC is that it provides a venue for teacher learning. In the previous section, the results of the second Rasch analysis of the stacked data showed that the three participating teachers in the Learning Study were placed higher up on the scale for measuring their TSPCK in the post-tests. The difference in the scores between the pre-tests and post-tests are analysed in this section in terms of their participation in the PLC, based on the transcripts of the planning and discussion meetings held.

6.4.1. The PLC Activities

During the course of the Learning Study, a planning meeting was held, as well as a discussion meeting to discuss the lesson after each teacher taught the collaboratively planned lesson. This included the pilot lesson, in which I as a teacher-participant taught the first lesson. Therefore, a total of four discussion meetings took place, one for each cycle of the Learning Study. Figure 6.6 provides a collage of photographs of the team in the meetings and teaching the lesson to provide a sense of the various activities that were outlined in detail in Chapter 5.

The activities of the PLC are summarised below.

(i) Planning meeting in which the teachers were introduced to the construct of TSPCK and the teachers developed a CoRe which was presented to the experts who provided feedback and guidance to finalise the pilot lesson.

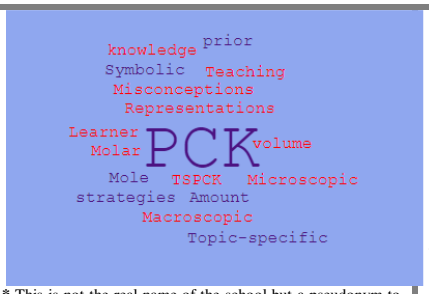
(ii) I as a researcher-participant piloted the lesson at Mansfield[24] High School as the first cycle of the Learning Study.

(iii) During the first discussion meeting, the results of the students' pre-tests and post-tests were discussed to help focus on what aspects need to be improved in the lesson.

(iv) Sipho taught the lesson in the second cycle of the Learning Study to his students at Mangosuthu Secondary School[1], which was followed by Tendani at Jukskei River Secondary school[1] and Sizwe at Rolihlahla Secondary School[1.]

(v) The PLC convened to discuss the students' performance, and the teachers' practice and ways to improve the lesson for the next cycle.

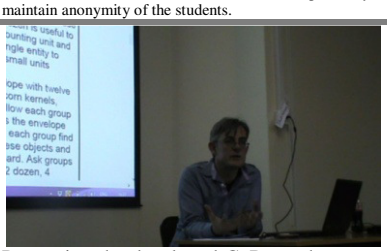
[24] This is not the real name of the school but a pseudonym to maintain anonymity of the students.



* This is not the real name of the school but a pseudonym to maintain anonymity of the students.

Workshop facilitated by the researcher introducing teachers to TSPCK in stoichiometry

Sipho, Tendani and Sizwe working on developing adapted CoRe in the workshop



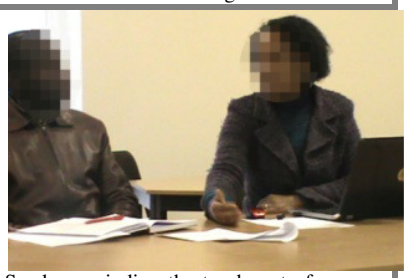
Presenting the developed CoRe to the team of experts

The experts providing feedback and suggestions for the CoRe

Teaching the pilot lesson to Grade 11 students at *Mansfield High School

Presenting the results of students' pre-test and post-test scores to facilitate discussion in the first discussion meeting

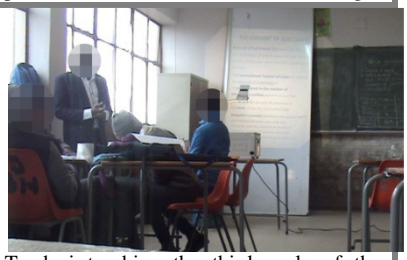
Tendani discussing his views on the pilot lesson in the first discussion meeting



Sandra reminding the teachers to focus on aspects of TSPCK when discussing the pilot lesson in the first discussion meeting

Sipho teaching the second cycle of the Learning Study at Mangosuthu Secondary*

Team discussing Sipho's lesson in the second discussion meeting and suggesting ways to improve and shorten the lesson.



Tendani teaching the third cycle of the Learning Study at Jukskei River Secondary*

Team discussing Tendani's lesson in third discussion meeting and reconceptualising the lesson based on students' pre-test and post-test scores.

Sizwe teaching the fourth cycle of the Learning Study at Rolihlahla Secondary*

Team discussion lessons learnt from the process as members of the PLC in the fourth discussion meeting

Figure 6.6: Collage of word cloud of common terms used in meetings and photographs showing members of the PLC engaging in the various activities of the Learning Study cycles

6.4.2. The Discussions in the Meetings of the PLC

In order to get a better understanding of the three teachers' movement up the logit scale from the stacked Rasch analysis described in the previous section, the qualitative data from the meetings were analysed. Chapter 3 provides a comprehensive description of how the meetings were coded in *Atlas.ti*. According to Guetzkow (1950), coding typically involves two operations, namely setting up the category sets to classify the data, as well as separating the qualitative data into units. The data from the transcribed meetings was coded at four different levels. The first involved identifying the participant. The second level of coding coded 'talk units'. These talk units were further categorised in TPK&S units, including TSPCK. Finally, the TSPCK talk units were further categorised into the five components of TSPCK. This subsection provides a detailed account of how this data was analysed.

In Chapter 5, a working definition for a PLC was provided, which included two critical aspects related to the interrogation of practice. These were that a specialised knowledge base was used to do so and that learning occurs through the discourse in the community. The coded data in *Atlas.ti* was therefore analysed using the 'codes primary documents table'. This table was used to determine the predominance of the three different coding units, viz. talk units, TPK&S units and TSPCK units in each of the five meetings and hence the type of discourse in each meeting. The discourse in the planning meeting and the discussion meeting after each cycle is plotted as a line graph below in Figure 6.7 to show the trends in discourse in each meeting.

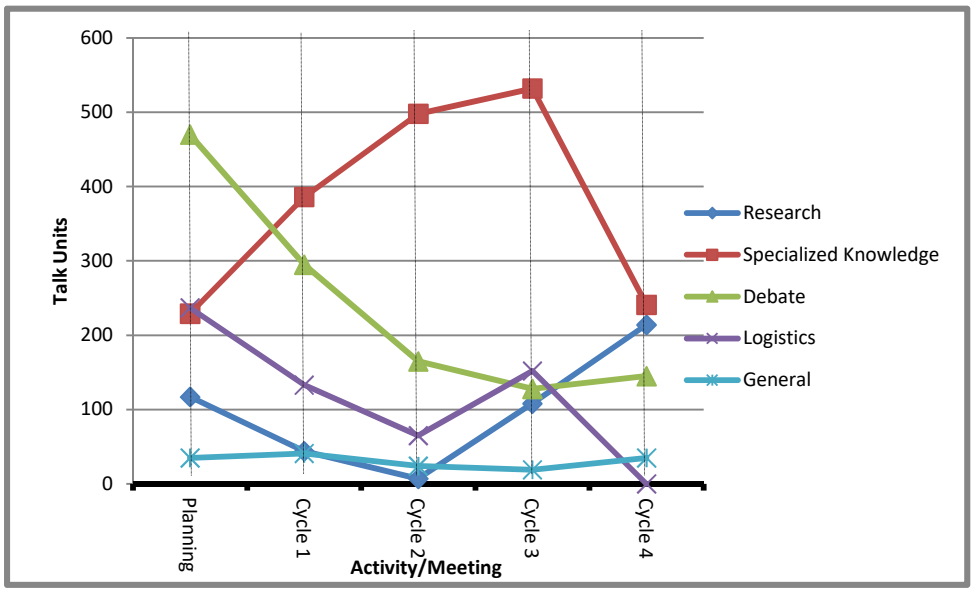


Figure 6.7: Line graph of talk units in each meeting of the Learning Study

As is evident in Figure 6.7, the planning meeting had almost five hundred debate talk units, as the team argued and cajoled each other on teaching approaches, to use, which aspect of stoichiometry to cover in the lesson, and discussed the alignment of aspects of the methodology of each of the participants' own research projects within this study. Over the course of all the meetings, the number of talk units related to debating decreased, as the team became more aligned with each other and were persuaded of the benefits of using the construct of TSPCK in planning the lesson. Much of the debate centred on defining misconceptions, why a conceptual approach to teaching stoichiometry was preferred over an algorithmic approach and which teaching approaches would be the most suitable for our purposes. Just over a hundred talk units related to aspects of research, to familiarise the teacher participants with the research process as they prepared their own research proposals. Over the course of the meetings, the talk units related to research declined until cycle 3, where aspects of data analysis were discussed for each of the participating teachers' own research. In terms of the logistics related to organising students for the lessons, resources and dates for the lesson, there were an equal number of talk units to that of the specialised knowledge in the planning meeting, as we broadly planned for different cycles. This is, however, slightly deceptive since many of the talk units for the specialised knowledge presented by the experts consisted of longer interactions (see Figure 6.8) when compared to the talk units for logistics. Over time, through each cycle of the Learning Study, as the team became more organised, there were less talk units related to logistics. Over the course of the meetings, the number of talk units related to the specialised knowledge increased, as the discussion of the lessons and brainstorming ways of improving the lesson centred on the construct of TSPCK. It is the talk units related to the specialised knowledge that deserve further attention. The construct of TSPCK was positioned in the TPK&S model at the level of collective PCK, or TSPK (see Figure 2.5). The instruments completed as a pre-test and post-test by the participating teachers measured TSPCK therefore the discussion of these components in the meetings needed to be analysed to account for the teachers' change in scores.

Figure 6.8 shows the coded units for the specialised knowledge 'talk units' shown in Figure 6.7. Each of the specialised knowledge talk units were categorised into units relating to the TPK&S model, with the TSPCK component categorised further into the five components of TSPCK. In Figure 6.8, the first graph illustrates the trends in the discussion related to the

TPK&S model, labelled as TPK&S units. As is evident in the graph, approximately 230 TPK&S units are present in the planning, meaning that of the specialised knowledge talk units, shown in Figure 6.7, most of the discussion related to TSPCK.

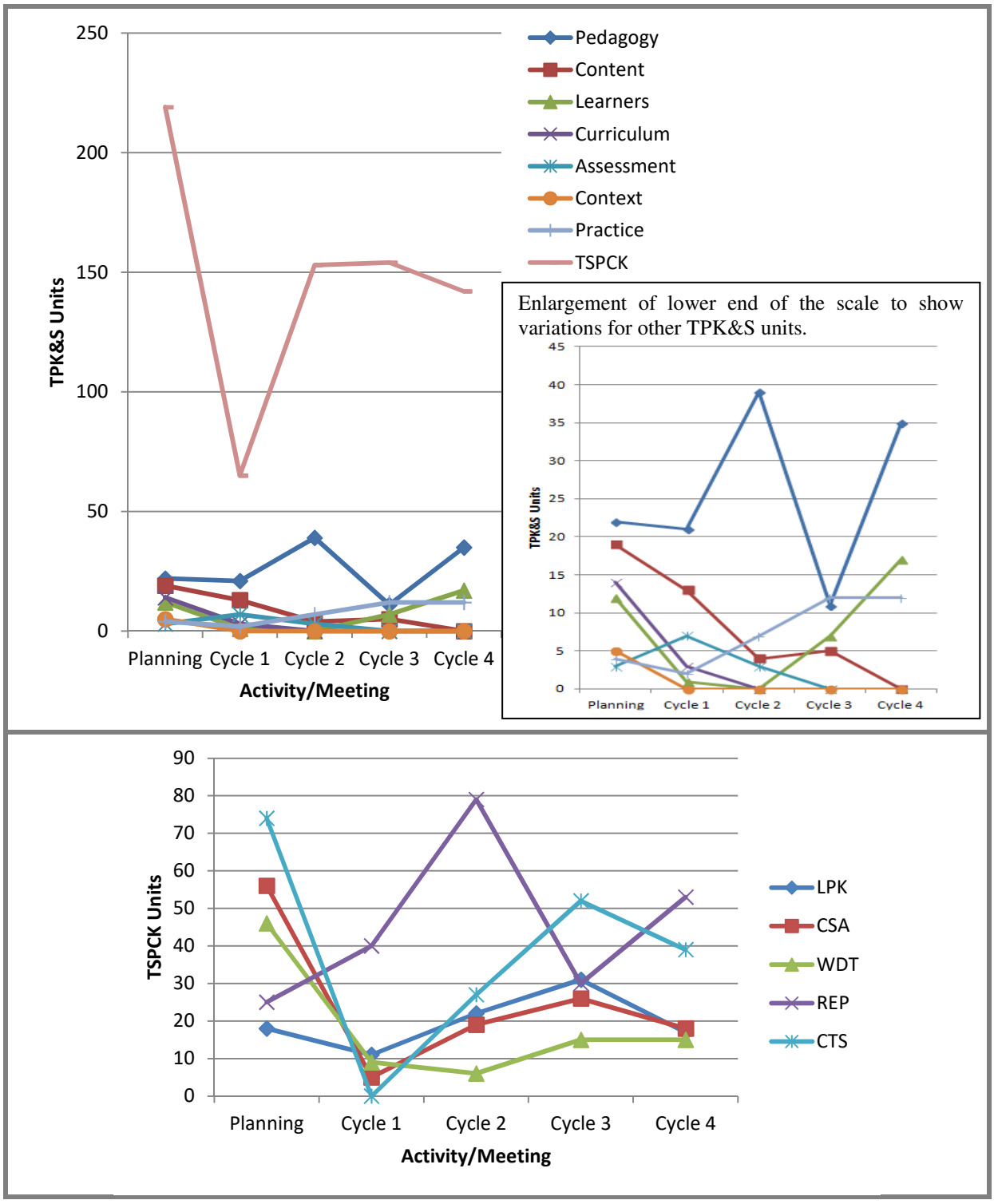


Figure 6.8: Graphs of TPK&S units and TSPCK units from double and triple coding of the specialised knowledge talk units

During the course of the meetings, aspects related to pedagogical knowledge, content knowledge, curriculum knowledge, assessment knowledge and knowledge of learners were discussed. In the first meeting, the context of learners and the schools was also discussed. In the discussion meeting after the first cycle, the number of TPK&S units related to TSPCK declined, as the teachers focused on surface issues in the lesson. However, this was rectified in the meeting as Sandra, one of the experts, reminded the participants of critically engaging with the lesson in terms of the TSPCK components, as is evident from the quote extracted from that meeting.

Sandra (line 180): *I'm just worried that we don't just go only at a surface level and fix the tiny things. When we look at that video I would like to see a TSPCK episode. I want us to see components working together. Because that's what makes TSPCK.*

The second graph in Figure 6.8 shows the breakdown of the TSPCK components discussed in each meeting.

It shows the TSPCK units from the triple coding of the TPK&S units that focused on TSPCK units. The patterns indicate that, in the planning meeting, CTS, CSA and WDT comprised much of the discussion when talking about TSPCK. The drop in CTS was due to the surface discussion the participating teachers engaged in, which Sandra highlighted in this meeting. After this admonishment, the discussion in subsequent meetings focused more on REP and CTS. LPK and WDT, although not as prominent in the discussion meeting after the first cycle, shows an increase in terms of TSPCK units as we discussed reasons for students' lack of performance in the pre-test and post-test they completed before and after the lesson in subsequent meetings. The patterns in this graph will be discussed further when looking at the individual performance of each teacher in the TSPCK Instruments in stoichiometry in the next section.

This subsection has focused on what was discussed in the planning and discussion meetings by representing the talk units over time. The specialised knowledge talk units (see Figure 6.7) clearly indicate that practice was interrogated using the construct of TSPCK (see Figure 6.8). In the next subsection, the participation of the different team members is discussed.

6.4.4. The Level of Participation in the PLC by the Three Teachers

To determine the extent of participation, that data was analysed using the 'code co-occurrence tables'. The latter shows all the codes that co-occur across all the meetings

(Friese, 2013). The participants were selected as column headings, the different talk units were selected for the rows and the analysis generated a cross-tabulation of all the codes, as shown in Figure 6.9.

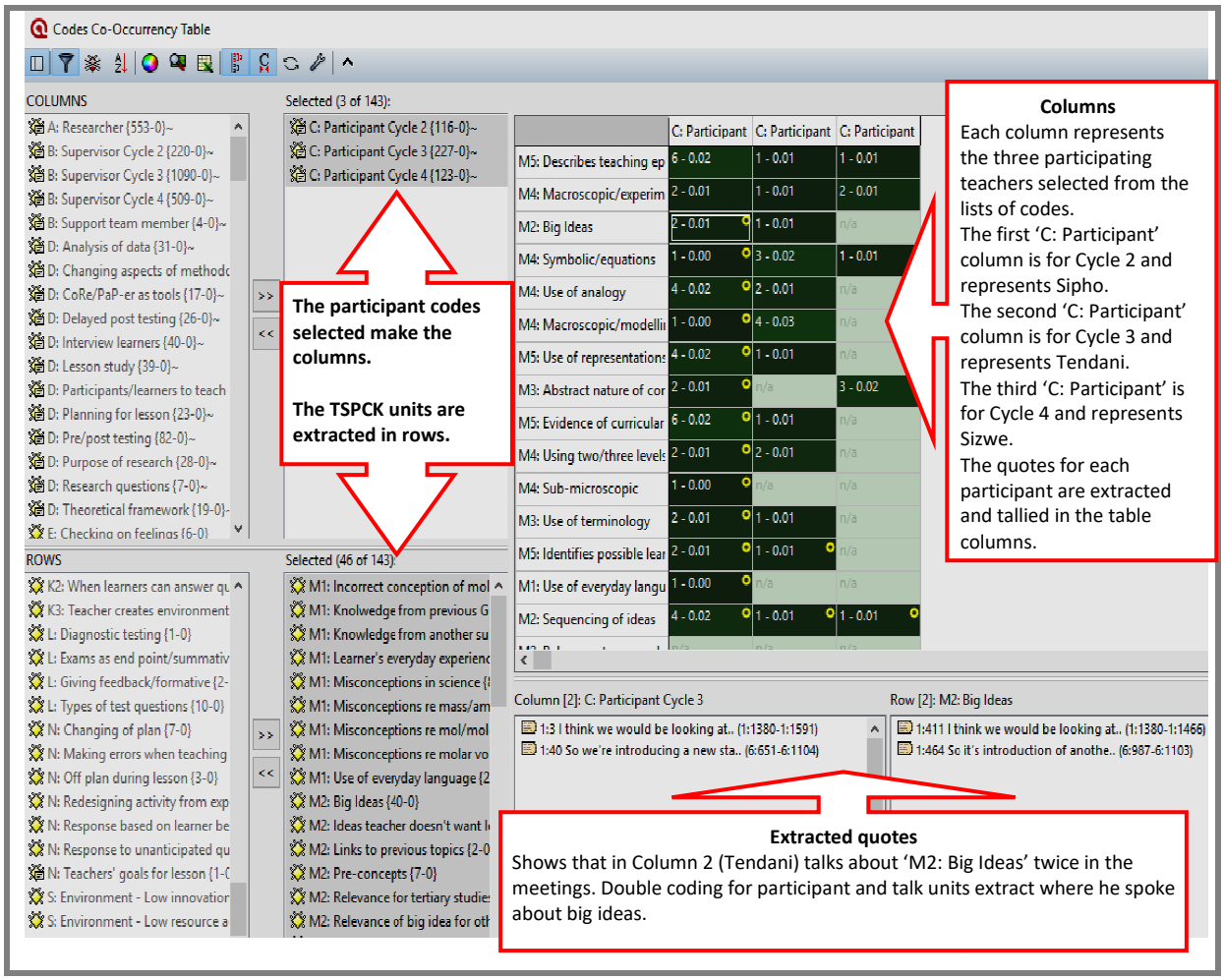


Figure 6.9: The generation of a cross tabulation of all codes in *Atlas.ti* from the transcripts of the meeting of the PLC

From the code co-occurrence table, a clear picture of each team member's contribution to the discussions could be determined. The bar graph in Figure 6.10 provides a picture of the participation of the teachers, and the experts, working together as both practitioners and researchers (Jaworski, 2008). The first bar in Figure 6.10 represents the total number of talk units by each team member, including aspects of research talk. The second bar represents talk units excluding research and includes general conversation and logistics about the Learning Study. The third bar is extracted from the second bar and includes talk units only related to TPK&S model including TSPCK. The fourth bar are the talk units related specifically to research, as expert members discussed aspects of the participating teachers' own research.

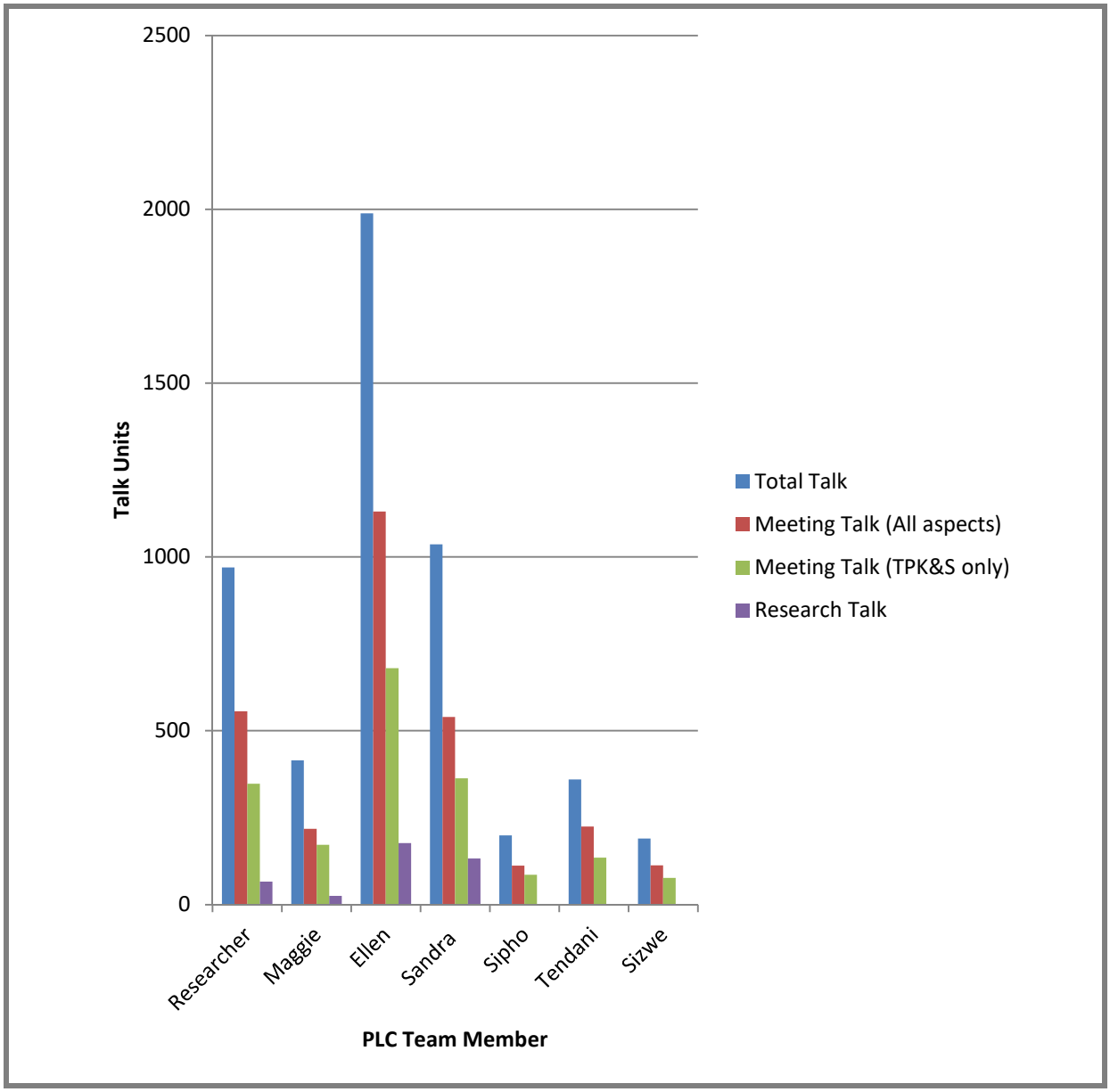


Figure 6.10: Bar graph to show the participation of each team member of the PLC in terms of talk units

As is evident in Figure 6.10, the expert members participated in the discussion to a far greater extent than the participating teachers. This, according to Jaworski (2008), is often due to the power and hierarchy tension associated with collaboration between teachers and teacher educators. This was summed up by Sipho in the exit discussion and captures the essence of this tension.

Sipho (line 10): *At first there seemed to be a gap between us and our supervisors. Initially there were very few contributions coming from us. But as time went on, because of the relations we had, I think we began to feel comfortable and contribute more.*

An analysis of the participation from the co-occurrence tables for the first three cycles of the discussion meetings, where the talk focused on improving the lesson, indicates that this was just a perception. Figure 6.11 is a bar graph that plots as a percentage the total talk units by the participating teachers and the experts. As is evident from the bar graph, their participation was fairly constant at under twenty percent of the total talk units compared to eighty percent by the experts in the discussions, although there was more participation from the teachers during the second cycle discussion meeting.

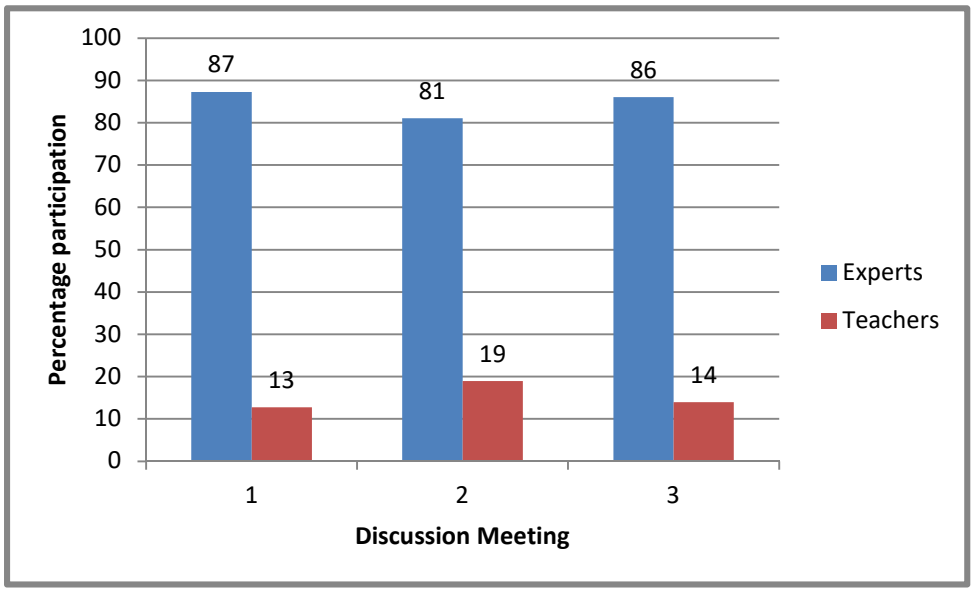


Figure 6.11: Percentage participation in discussion meetings for Cycle 1, Cycle 2 and Cycle 3 of the Learning Study

However, despite the skewed levels of participation in the meetings between the expert members of the PLC and the participating teachers, this does not take into account the actual teaching of the lesson. It was in the lesson that the teachers put what was discussed, and planned and implemented aspects of TSPCK, into practice. Sipho acknowledged the challenge inherent in planning a collaborative lesson and how the discussions from the meetings guided the implementation. He summed this up succinctly in the last discussion meeting.

Sipho (line 472): *It's not easy to implement a lesson planned as a group. You want their input to guide you and you have to keep in mind the issues we discussed. Some things come to the fore, others, they disappear.*

The interactions in the meetings and the discussion of classroom enactment can also contribute to the teachers remembering prior learning in their teacher training. More

specifically, according to Sizwe, aspects that were important, but often not focused on when teaching in schools are demonstrated in what he said in the exit discussion.

Sizwe (line 10): *Another thing, interaction with each other, because we've been in teacher training a long, long time ago helps. So when we interact with teacher education people especially, we remember some of the things we need to focus on.*

In this section, the analysis of the qualitative data related to the interactions in the meetings of the Learning Study have been discussed, in terms of talk units as coded in *Atlas.ti*. Although the meetings did not only focus on the specialised knowledge the PLC was using to interrogate practice, this knowledge, as measured in 'talk units', constituted a large proportion of the time of the meetings. In addition, although the experts often dominated the participation, the three participating teachers still learnt in the process, as is evident in their move up the logit scale discussed in this chapter. In the next section, a qualitative discussion of the teachers' improvement in areas from the pre-test to the post-test will be discussed by telling the stories of the three participating teachers in the form of vignettes. The vignettes will then be used to link teacher learning in relation to the interactions in the meetings.

6.5. Qualitative Analysis of Changes in Scores – The Story of Three Teachers

In Section 6.2, the change in the three teachers' pre-test and post-test scores on the TSPCK Instrument for stoichiometry was described. In this section, a qualitative analysis of the instruments to determine the extent to which their responses changed is presented. Supporting evidence from the pre-lesson interview, SRI, discussion meetings and the exit discussion were used to account for these changes in the responses to each item on the pre-test and post-test. These were used to develop vignettes that describe the differences between the pre-test and post-test scores. To avoid repetition in the vignettes, the changes or lack of change in scores are not discussed for each teacher but examples are extracted from one of the three teachers' instruments for each of the five TSPCK items. A full description of this analysis for each item is in Appendix 18. The subsection below outlines how the vignettes were constructed to tell the story of each teacher's learning,

6.5.1. Developing the Vignettes for the Teacher's Story

The vignettes to describe each teacher's learning consist of five aspects, with each aspect dealt with in a single paragraph of the vignette. These aspects, linked to the criteria for writing narratives (Dollard, 1935 in Polkinghorne, 1995) include:

(i) The introductory paragraph to provide some context related to the teacher's learning (Barter & Renold, 1999) that outlines the teacher's epistemological and self-efficacy beliefs and what they hoped to learn through participation in the PLC;

(ii) A description of the improvement or lack of improvement in CSA, particularly the big ideas selected and importance of teaching stoichiometry;

(iii) A description of the changes in scores, or lack thereof in the LPK and WDT items;

(iv) A description of the changes in score in the REP item, and;

(v) A description of the changes or lack thereof in score in the CTS item.

(i) Teacher's Epistemological Beliefs and Self-Efficacy

Each vignette for the teachers begins by providing an outline of the teachers' beliefs, since these act as filters in the development of their TSPK (Gess-Newsome, 2015). The teachers' epistemological beliefs about the teaching and learning of science were gleaned from a written questionnaire, using the interview questions used by Luft and Roehrig (2007). This was done when the teachers completed the pre-test. The decision to do this in a written questionnaire was based on the already heavy interview schedule. The questionnaires were analysed before the video-SRI, in order to seek clarification to the teachers' responses if necessary. For example, Figure 6.12 shows Tendani's response to a question in the beliefs questionnaire. His response was analysed as instructive, using the beliefs grid developed by Luft and Roehrig (2007). However, to clarify what was meant by mediate learning, this question was asked in the video-SRI interview (see Figure 6.12)

Figure 6.12 also shows an extract from the self-efficacy questionnaire (Tschannen-Moran *et al.*, 1998). The scores were determined by finding the average for three factors, namely, efficacy motivating student learning, efficacy in implementing instructional strategies and efficacy in classroom management. This was used to get a qualitative sense of the teacher's own feelings towards these three factors of self efficacy. As is evident in Figure 6.12, Tendani was extremely confident in his abilities to implement instructional strategies and possibly over-confident in this area. The beliefs questionnaire and self-efficacy questionnaire

were used to introduce each teacher to set the scene for their vignette and provide a context for each teacher's learning (Barter & Renold, 1999).

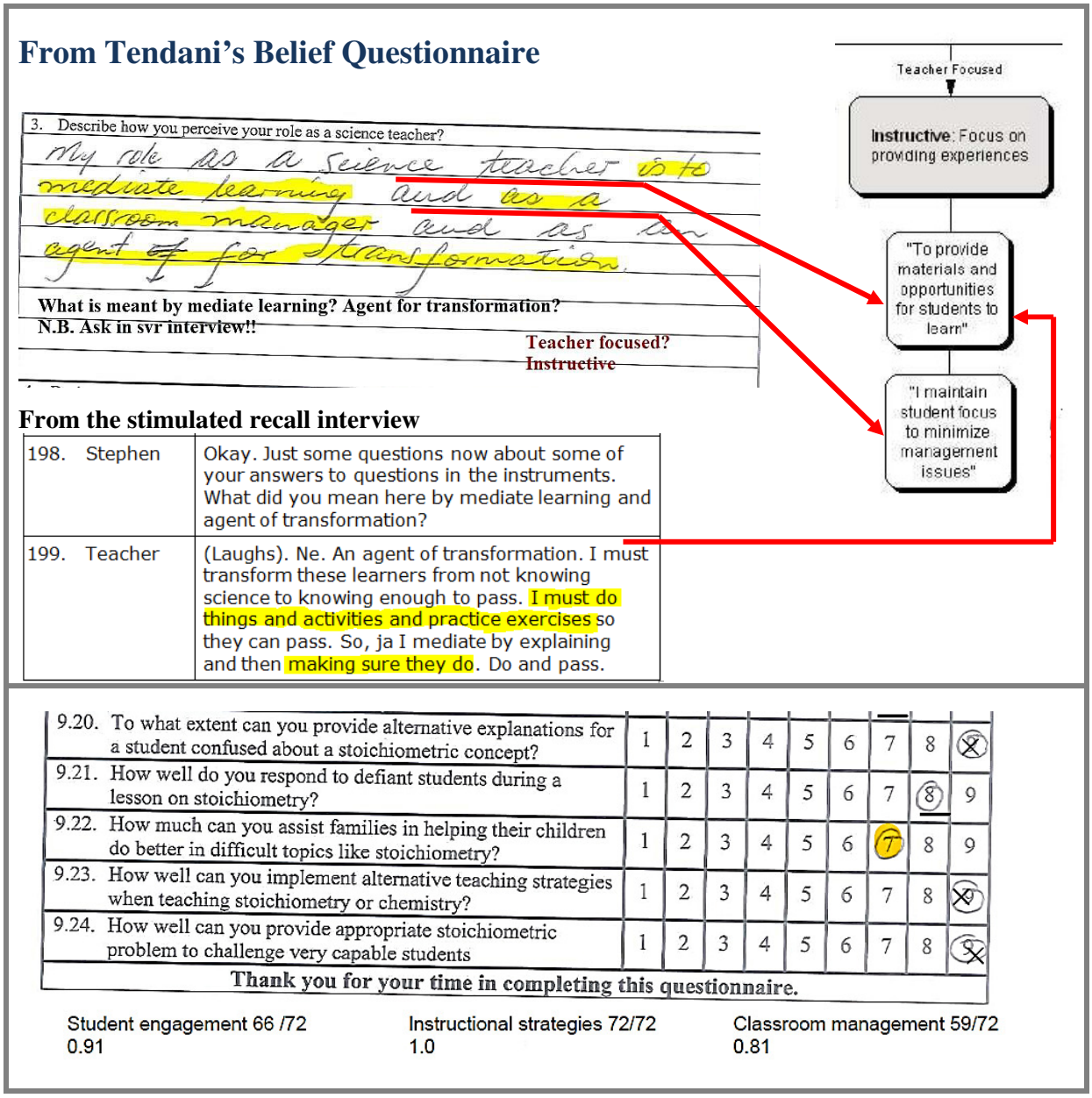


Figure 6.12: Extracts from Tendani's beliefs and self-efficacy questionnaire used to develop context for vignette

All three teachers, other than the common purpose of completing a research project required as part of their Master's degree, also had very different reasons for learning. This reason is included in the last part of the introduction of each vignette. Sipho was focused on finding ways to improve his practice. This was very evident in the last discussion meeting when he summarised his expectations and stated how he would implement what he had learnt.

Sipho (line 437): *That which we got here, I want to implement it in my classroom. I wanted to know how can I improve my practice. I plan to engage with learner difficulties in the following terms when I teach stoichiometry.*

Tendani, on the other hand, focused more on how he could share what he had learnt personally with his colleagues. This was also evident in his SRI when he was asked what he had learnt.

Tendani (line 195): *Generally, me I've learnt a lot, like I feel I'm empowered. I feel confident. I feel on top of the situation, and, you know even though you had to persuade me to try this. I've never used the word amount of substance. Now, after these discussions, I'm now always using the word amount. I have shared this with my colleagues in my cluster and we want to see if we can use these ideas to get better examination results.*

Sizwe's focus for learning, as garnered from the exit discussion, was for his own enrichment and development. This development was both as a practitioner and as an emerging researcher.

Sizwe (line 23): *Personally I'm more confident with teaching stoichiometry than probably any other section in the syllabus, because of the engagement that we've had. From my own research, we did this for research purposes and others are doing it for professional development. They can learn a lot from the way that we did it, especially on topic specificity.*

(ii) Curricular Saliency and Selecting Big Ideas

The second part of each vignette focuses on the teachers' scores in the pre-test and post-test related to the item CSA, which consists of four sub-items. These include identifying the big ideas, indicating how the big ideas are linked by constructing a concept map, identifying important pre-concepts that need to be taught before teaching the various big ideas and the importance of knowing the big idea. Sizwe's post-test score showed the largest improvement in this item. So he will be used as the example to highlight how this part of the vignette was developed.

Figure 6.13 illustrates the big ideas and the sequence of the ideas in a diagrammatic format, as extracted from Sizwe's pre-test and post-test instruments. Initially, Sizwe only identified subordinate concepts as big ideas and in the post-test, he correctly identified two big ideas (see Figure 6.13). Interestingly, the reason Sizwe provided in the pre-test for selecting these concepts highlighted the same alternative conceptions the lesson of the Learning Study was designed to challenge. His reasons as extracted from his pre-test, stated: *"The mass gives an*

idea about the amount of substance, thus enables calculation of molecular mass. Molar mass relates the mass of substances to it mass in grams." In his post-test, Sizwe selected the mole and concentration as big ideas and his reasons highlight how the planning of the lesson around developing an understanding of the mole, helped him link the mole concept to the concept of concentration. He stated that: "*The mole concept helps to understand the SI unit for amount of substance. But when a particular amount of substance is a solute, then we can talk about its concentration as the number of particles per unit volume.*"

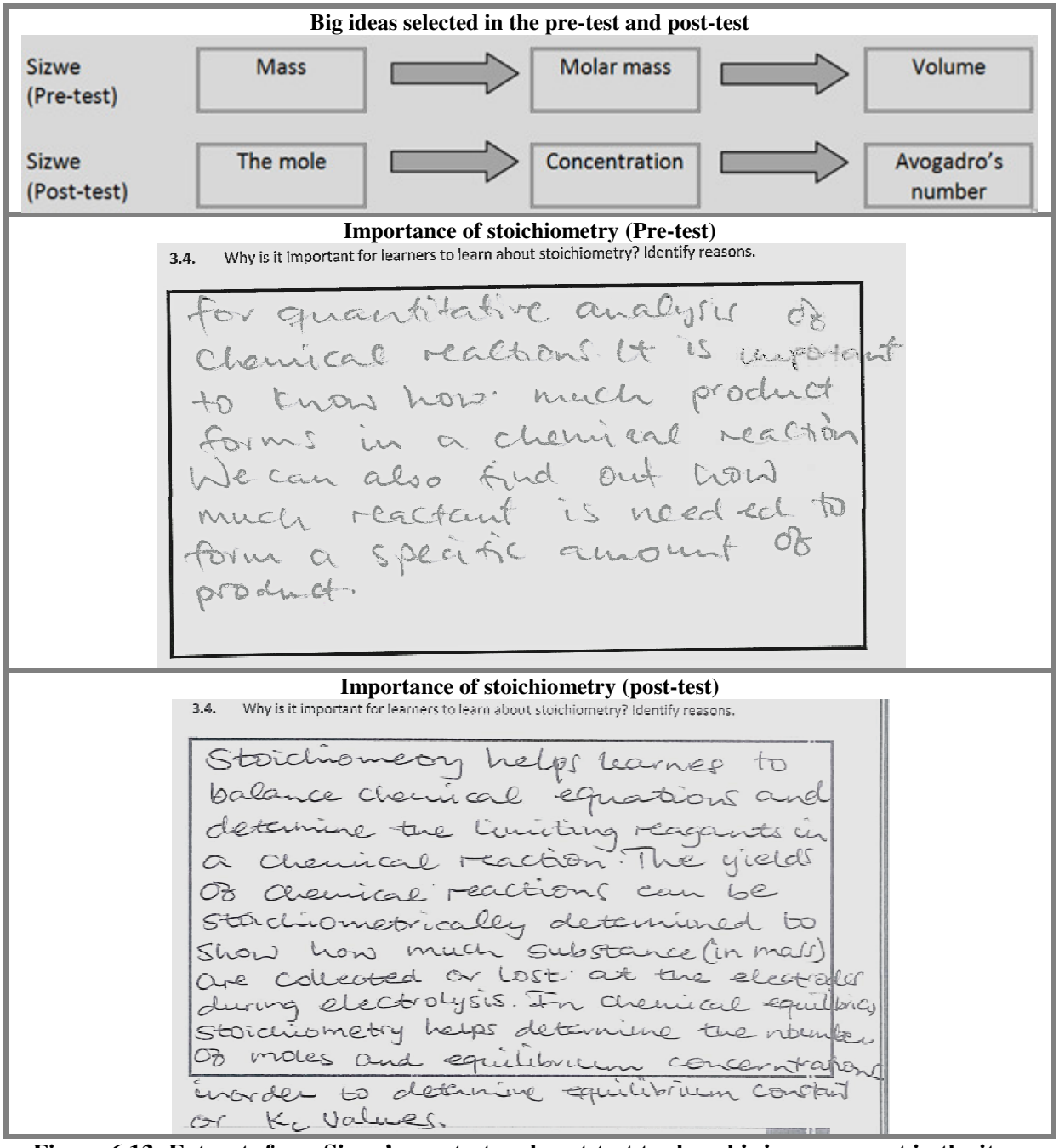


Figure 6.13: Extracts from Sizwe's pre-test and post-test to show his improvement in the item CSA

In the pre-test, his response on the importance of teaching stoichiometry only focused on the importance of the stoichiometry in quantitative analysis (see Figure 6.13). However, in the post test, his response included conceptual scaffolding for other topics, hence his improvement in this item (see Table 6.1). It was his selection of the big ideas and greater engagement with the item that resulted in the improvement in his score and this is described in the vignette.

(iii) Learner Prior Knowledge and What is Difficult to Teach

The third part of the vignette focuses on improvements in the scores to the LPK and WDT items. All three teachers improved their LPK scores, based on the reasoning for their selection of the responses. For WDT, Sipho's score remained static since he already had a good grasp of this component, with Tendani showing the greatest improvement (see Table 6.1). In fact, Tendani's response to the item WDT was flagged by the Rasch analysis as a misfiting person, in that his response was better than his expected score based on his person measure (see Figure 6.1). Since Tendani's improvement is unexpected, in terms of the Rasch model, his pre-test and post-test are examined here to highlight how this part of the vignette was developed. Tendani's responses to the LPK item and the WDT item are shown in Figure 6.14.

Firstly, in terms of the item relating to LPK, Tendani's response in both instruments is shown in Figure 6.14. This figure shows he selected the best option in both instances. However, in the pre-test he only emphasises the fact that STP applies to gases for the first question. He only provides standardised knowledge in his reasoning. However, in the post-test, he not only confronts the misconception but expands on his reasoning, which goes beyond just providing standardised knowledge. He specifically states that even though the cubes have the same volume, molar volume only applies to gases. He expands on this explanation and states that for liquids and solids, students would need to calculate the amount of substance (see Figure 6.14). It is for such reasoning that he improved his score in the post-test.

As is evident in Figure 6.14, Tendani's response to the WDT item also shows a greater level of engagement. In the initial planning meeting, Tendani stated that his strategy for teaching stoichiometry was algorithmic and focused on helping students cope with difficulties in the mathematical application of stoichiometric calculations. He said: "*My strategy when I'm teaching is for exams. First to define what this mole is and then from there, we break to*

calculations. There is this memory aid, the triangle nê. If you are not very good in calculations use this memory aid triangle." However, in response to the item WDT in the post-test, he gave detailed reasons related to students' conceptual understanding of concepts that were difficult to teach. In his pre-lesson interview, when asked what made stoichiometry difficult to teach, he responded by stating students' understanding of the word amount was problematic since "*they associate the word amount with mass, or with volume*". This is in stark contrast to his response in the pre-test, where he did not even write a response as he did not consider the amount of substance or its unit, the mole, difficult (see Figure 6.14). This shift in thinking was clearly evident in Tendani's change in scores for this item. This is described in Tendani's vignette and the changes for each teacher's response to these items in the pre-test and post-test was analysed in the same way to develop their vignettes.

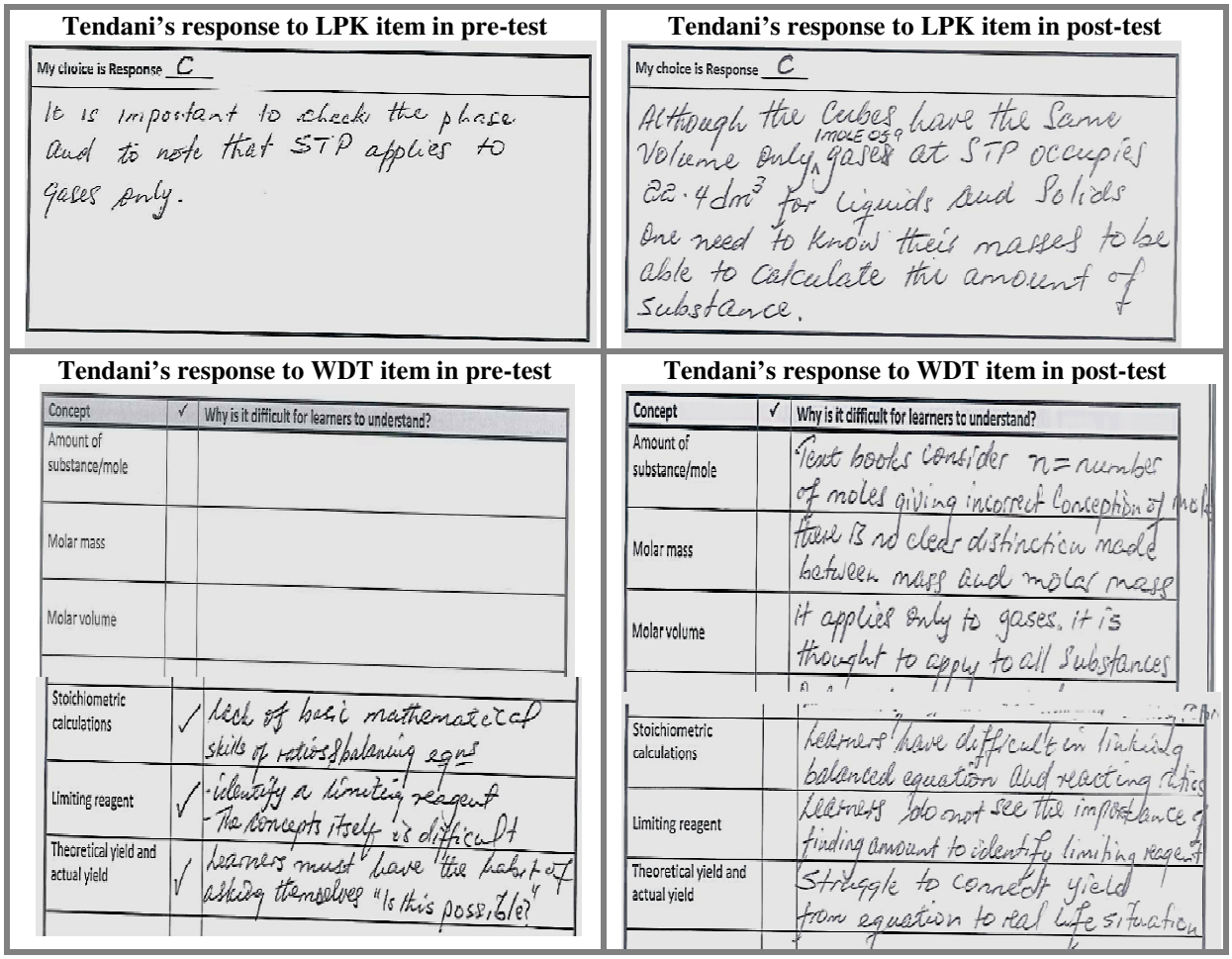


Figure 6.14: Tendani's responses the LPK and WDT items in the pre-test and post-test

(iv) Representations

The penultimate part of the vignette looks at the changes in score to the item related to representations. Both Sipho and Sizwe improved from basic TSPCK to exemplary TSPCK in

this item. Sipho selected the same representation in both the pre-test and post-test but did not provide explanatory notes in the pre-test. In the pre-test, Sizwe selected the symbolic representation, the formula triangle but in the post-test he selected the representation that included the macroscopic, submicroscopic and symbolic level. Therefore the qualitative analysis of Sizwe's instruments is described. The reason for this is based on Sizwe's comments he made about what had been difficult for him. In the last discussion meeting, he admitted that it had been a challenge for him to work with the three levels of representation.

Sizwe (line 475): *I was thinking that it has always not been easy to do the representations and actually link microscopic to macroscopic. I found out that in the lessons that we taught where we were supposed to bring in that other [submicroscopic] explicitly, especially when we looked at the periodic table and those four substances. It's a challenge to teaching science.*

In the post-exit discussion, he explained how he had realised the importance of using the three levels of representation together to help explain concepts.

Sizwe (line 475): *Calculations are very familiar to learners. But when you start with macroscopic representations, you are talking about something which the learners are familiar with. Then when you go to the microscopic representations you are going to something which they do not think about every day. Like if we had to dissolve a solute in a solvent, like a teaspoon of sugar in water. We'll have a concentration of this much, easy to calculate if you know the volume and mass. But it's not that it has disappeared but things dissolve. They can taste the sugar. I think it works to bring them to see the submicroscopic to understand the sugar is still there. Then do the symbolic, which is the scientific part.*

Sizwe's response to the item on REP is shown in Figure 6.15. In the pre-test, he selected representation 2, the formula triangle, specifically because it allowed students to easily do stoichiometric calculations. In the post-test, he specifically selects representation 3 because it is multi-faceted (see Figure 6.15). In his explanation, he brings in the size of the cubes, the macroscopic aspect. He talks about the particles, the submicroscopic aspect and links this to the symbolic balanced equation. He even describes how from the mass, the amount can be calculated, linking the macroscopic property of mass to the symbolic level in the form of calculations. Further evidence for the use of representations was obtained from the CoRes done by the two of the three teachers. An extract of Sizwe's CoRe is also shown in Figure 6.16 and provides further evidence of the integration of the three levels of representation.

This is described in Sizwe's vignette and the data was analysed in the same way for the other two teachers to develop their vignettes.

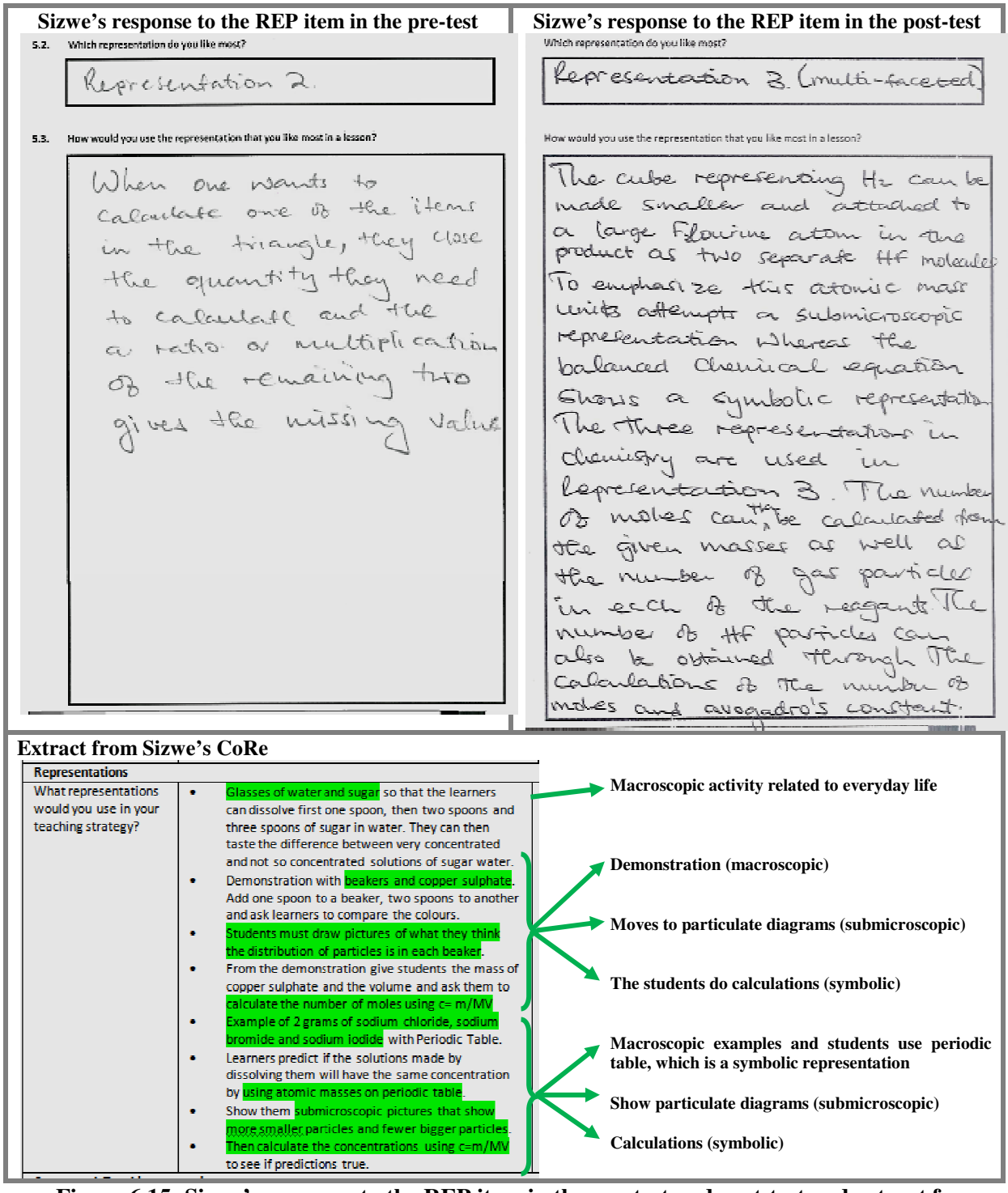


Figure 6.15: Sizwe's response to the REP item in the pre-test and post-test and extract from CoRe after the Learning Study

(v) Conceptual Teaching Strategies

The last paragraph of the vignette describes the change in scores for the CTS item. This item requires teachers to integrate the other components into an explanation of how to correct a student error. Both Sipho and Sizwe improved in this item but both only used symbolic representations in their teaching strategies. However, when compared to their responses in the pre-test, they were more methodical in their explanations, indicating they considered aspects of curricular saliency and explicitly identified the learner errors, and based on the rubric scored 3. Sipho's strategy in the post-test included active learner participation. For this reason, his post-test will be discussed to provide evidence of how the vignettes were compiled. Extracts from his response are included in Figure 6.16 on the next page.

Although Sipho still only uses one level of representation in his response to the post-test, he shows evidence of curricular saliency in the sequencing of ideas (see Figure 6.16). There is evidence of encouraging student participation. These two factors are the reason he scored 3 rather than 2 (see Table 6.1). The evidence of learner participation is linked to Sipho's own research project, which was a self-study. For his research, he had to do readings related to the 5E teaching strategy (Bybee, 2009) and was therefore more aware of engaging students. When reporting on his self-study, he wrote that it did help him to some extent because when he actually taught his lesson, he implemented the first three stages of the 5E method.

> **Sipho** (from report): *This had been part of the plan that I executed as I used the students' prior instruction conceptions in order to dispel some misconceptions related to the mole. This was evidenced by the engagement of my learners with everyday life experiences about some terms and how such terms were related. For instance the relations of the term amount with volume and size. Learners then moved on to engage in activities and later gave explanations or discussions on their findings during the enacted lesson. These are the initial stages of Engagement, Exploration and Explanations in Bybee's 5Es instructional strategies.*

This evidence is outlined in Sipho's vignette. The responses to this item for Tendani and Sizwe were analysed in the same way to develop their vignettes.

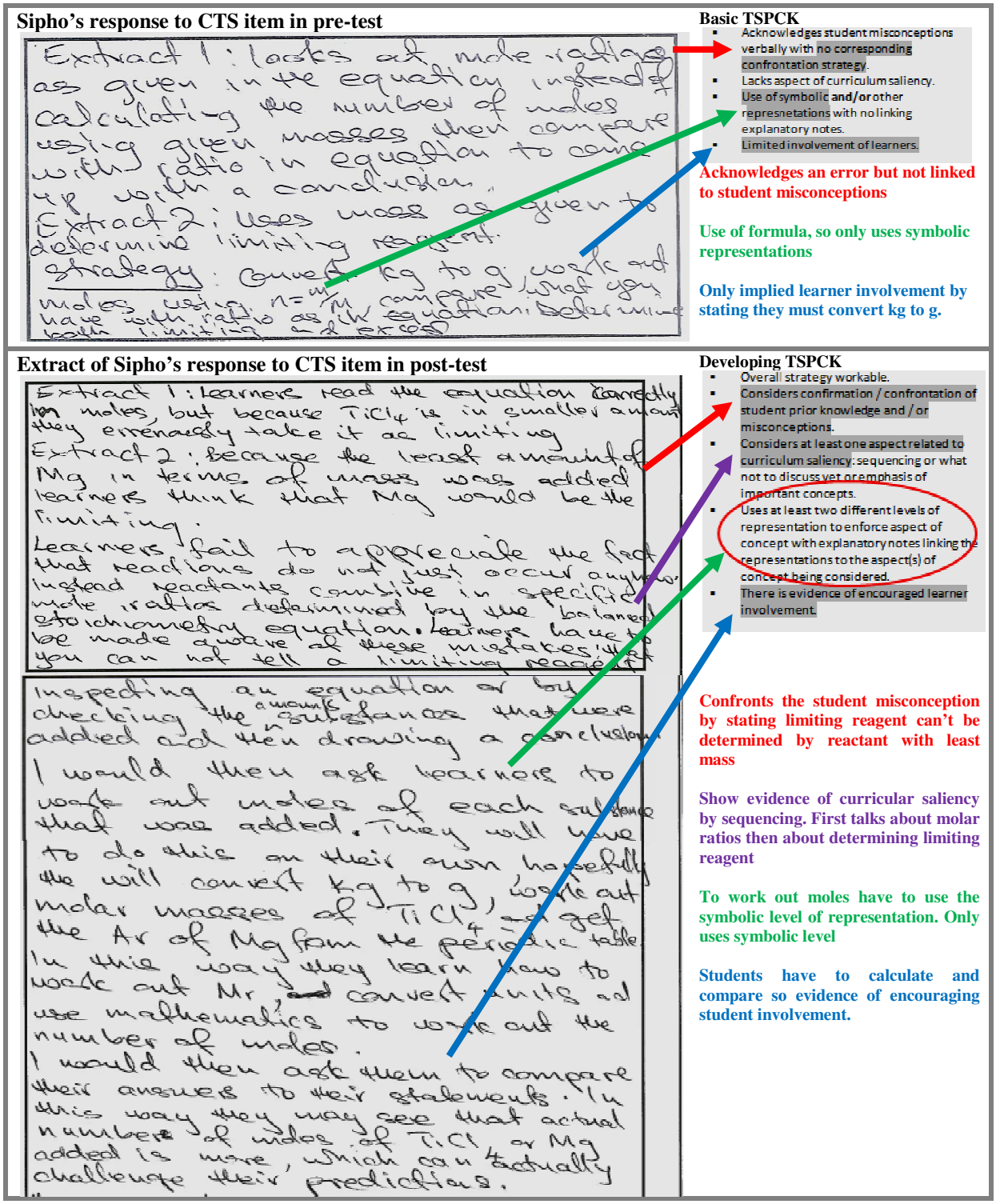


Figure 6.16: Sipho's response to CTS item in pre-test and post-test

In this subsection, a detailed description has been provided by showing examples of how the pre-test and post-test instruments, and the belief questionnaire were analysed to write up the vignettes that follow. Each tells the story of how each participant's scores for the pre-test and post-test were determined. Supporting evidence has been drawn from other data sources to

provide possible evidence to account for the changes in score. The first vignette tells Sipho's story.

6.5.2. Sipho's Story

In the subsection above, a detailed description was provided of how the vignette that tells Sipho's story was compiled. In the subsection above, Sipho's response to the CTS item in the pre-test and post-test was used as an example for how the last part of the vignette was constructed.

Vignette One: Sipho's Story

At the beginning of the study, Sipho's epistemological beliefs about teaching are instructive, as he sees his role as a teacher as one of helping his students develop an understanding of science concepts. He also feels that his role includes helping students to perform well in standardised assessments and develop procedural skills. In his classroom, he tries to maximise learning by doing demonstrations and creating an environment where students can ask questions and participate in class discussions. In terms of student learning, when students can explain concepts and answer questions, he generally moves on to teaching new concepts. He does feel restricted by the prescribed work schedule which he follows. As a science teacher, Sipho feels that his classroom management and ability to implement effective instructional strategies are very good. However, he feels he only has some influence over motivating student engagement. Sipho's main reason for being part of the PLC was to find effective ways to improve his practice. Completing the pre-test and post-test was a way for him to gauge if his participation in the PLC developed his knowledge as a stepping-stone to improving his practice.

In his pre-test, Sipho only selected the mole as a big idea, with his two other ideas being stoichiometric calculations and quantitative analysis methods. In his sequence, he began with stoichiometric calculations and then the mole, with quantitative analysis methods being his third idea. His reasoning for starting with stoichiometric calculations, was based on students' understanding the importance of the balanced chemical equation. Once they understood the importance of balancing equations, the mole could be used to calculate quantities like the mass of substances, the concentration of solutions and the number of particles. This could then be practically applied in quantitative analysis methods. In the post-test, Sipho selected the mole, Avogadro's number and stoichiometric calculations in that sequence. This time, his reasoning related to the mole being the basis for understanding the quantitative aspects of chemistry, and the link between a mole and the number of particles to understand reacting ratios. He felt if students grasped these two ideas, his final idea, that of stoichiometric calculations would allow all other concepts to be understood. When asked about his selection

in the post-test, Sipho felt that the focus on the mole concept in the Learning Study overshadowed the other ideas, like concentration and limiting reagent. He suggested that this was the reason he did not include them in the post-test. For the importance of stoichiometry, Sipho, in both the pre-test and post-test, provided reasons related to the application of stoichiometry and its importance in other topics, without listing particular topics. As a result, he showed no improvement in his curricular saliency knowledge.

Sipho's responses to the LPK items in the pre-test were very limited. For the equal cube problem, he selected the best response but limited his explanation to the standardised knowledge that molar volume only applies to gases. However, in the post-test, he explicitly said that even if you had one mole of the liquids and solids, they would not occupy a volume of 22.4dm^3. He also provided a detailed explanation that, in order to find the number of moles, the students would need to know the mass of each substance not in the gaseous phase. For the second item, that of equal masses of halides dissolved in the same volume of water, in the pre-test he did not select the best response, whereas in the post-test he did. For WDT in both the pre-test and post-test, Sipho provided a range of reasons, some focusing on student misconceptions, but many related to mathematical abilities and the abstract nature of concepts. This did not change in the post-test and he did specifically state that gate-keeping concepts, if not understood would contribute to student difficulties.

In both the pre-test and post-test, Sipho selected the representation that showed the macroscopic, submicroscopic and symbolic levels of representation. However, he did not provide any explanatory notes, beyond saying he would use it to teach balanced chemical equations and conservation of mass. Although both these concepts were identified by Sipho as important pre-concepts for the topic of stoichiometry, his notes did not explain how he would use the representation to explain these concepts. In the post-test however, he stated that the reason he selected it was because it showed the three levels of representation. He went on to explain that it could be used to teach molar volume of gases, reacting ratios in terms of volume for gases, the balanced chemical equation and the reacting particles. He also explained how it could be used to introduce the mole as a counting unit and in calculating the amount of substance. The different levels of representation were explicitly discussed in many of the meetings of the PLC and contributed to his understanding. Sipho's CoRe also listed the representations he would use when teaching concentration. These included beakers of different sizes to establish an understanding of volume, submicroscopic pictures to show different volumes and mathematical calculations. He did not, however, show how he would integrate the three different levels of representation when teaching concentration.

The item on CTS in the instrument required Sipho to bring the other components together in his response. In the pre-test he did not explicitly identify the student misconceptions related to the mass or molar ratios. In his response, he wrote down the formula and stated that students have to calculate the number of moles. He also mentioned that students have to convert

kilograms to grams, which provided some evidence of limited student involvement. In the post-test, he pulled together some of the components yet still outlined a strategy including symbolic representations only. He clearly identified the student misconception and confronted it by stating the limiting reagent can't be determined by purely selecting the reactant with least mass. Evident in his response were aspects of curricular saliency in the way he sequenced his explanation, by first discussing molar ratios before providing standard knowledge about the concept of limiting reagents. He also outlined a strategy in which students had to make predictions, do calculations and discuss their answers with their peers. This type of response was due to Sipho's own research focus. He was doing a self-study to improve his teaching practice and was required to use the 5E strategy, which encourages student participation. These aspects of his response contributed to his increase in score despite only using symbolic representations. Sipho would like to implement some of the strategies he was exposed to in the Learning Study to create a more learner-centred classroom environment but felt that time constraints and curricular demands would prevent him from doing so.

The above vignette provides a description of Sipho's learning by looking at his responses to the pre-test and post-test. The vignette in the next subsection provides a description of Tendani's learning in terms of his responses to the items in the TSPCK Instrument.

6.5.3. Tendani's Story

The vignette in this subsection was compiled in a similar manner to the one in the previous subsection that illustrated the change in scores in Sipho's pre-test and post-test. A detailed description of how the vignettes were compiled was provided in subsection 6.5.1. In this subsection, data from Tendani's beliefs questionnaire was used as an example to show how the introduction of the vignette was compiled. Data from Tendani's pre-test and post-test was used to show how learning in the items related to LPK and WDT occurred. Tendani's story is provided below in the second vignette.

Vignette Two: Tendani's Story

Like most teachers in South African schools, Tendani is limited by the work schedule when it comes to deciding when it is time to move onto the next topic. However, his epistemological beliefs about science teaching are typically instructive. He believes that students need to be focused on what he does before they can go on and work together in practising what he has taught. He sees his role as a teacher as transferring science knowledge and mediating learning through providing experiences, by using the teaching strategies he has gained over the years, either through training or experience. He believes that the students' workbooks are a good indication of how much learning has taken place. Tendani is extremely confident in

his abilities related to instructional strategies and engaging students in learning. He feels that, in terms of instructional strategies, there is no room for improvement but does feel he can improve in the way he engages students. Tendani also feels his classroom management to ensure effective learning is very good. In terms of his own learning, his confidence in his ability to implement his teaching strategies meant that Tendani had to be persuaded to try new approaches. In the end, he felt he had learnt a lot, especially in terms of nomenclature which he could share with colleagues. Completing the pre-test and post-test were a way for Tendani to measure his own learning.

In Tendani's pre-test, he selected the mole, Avogadro's number and molar mass as big ideas and, in his reasoning, specifically stated that the mole was an SI unit. Despite his understanding of the mole as a unit, Tendani never used the term amount of substance and always referred to the number of moles. Once introduced to the term, he made a conscious effort to talk about amount of substance and its SI unit, the mole. In the post-test Tendani selected the mole, mass and molar volume as big ideas. His reasoning related directly to the sequence of activities discussed in the meetings of the PLC, through the various cycles of the Learning Study. He reasoned that if students understood that the mole was the SI unit for amount of substance, then they would understand that from the mass of a substance the amount of substance can be calculated. His last idea was molar volume, and he linked the amount of gas to its volume. He explained that he selected these ideas because that is what he remembered most from the process of planning, teaching and discussing the lessons. Although Tendani only selected one big idea in both the pre-test and the post-test he felt that one of the most important things he learnt was the application of stoichiometry. He felt that if students understood the importance of a concept, they would understand why they needed to learn it. In the post-test, he not only stated that the topic was important for topics like acids and bases, but had important industrial applications, such as in the production of ammonia gas.

Tendani's improvement in the LPK and WDT items can be attributed to his level of engagement with both items. For the LPK item related to molar volume, in both the pre-test and the post-test, he selected the best response. However, his reasoning was far more detailed in the post-test. In the pre-test, he only provided standardised knowledge but in the post-test he met all four criteria in the TSPCK rubric for exemplary TSPCK. He confronted the misconception by saying that, even though all the cubes had the same volume, they did not all contain one mole. He specifically stated molar volume only applied to gases, thereby identifying the misconception. He also provided standardised knowledge, that one mole of a gas occupies a volume of 22.4dm^3 and went on to explain that the mass of the other substances is needed to find the amount. For the second item, in the pre-test he provided a very algorithmic response, whereas in the post-test, he explained that having the same mass of each substance does not imply they have the same amount. So even though his choice of

response was the same in both the pre-test and post-test, his focus in his reasoning was on the misconception. For WDT, Tendani did not even recognise the difficulty students had with the mole concept and those ideas he did select he considered difficult because of students' difficulty with mathematical reasoning. However, in the post-test, he provided reasons related to students' understanding of amount, and linked this understanding to other concepts in the topic. Tendani developed a deeper understanding of how misconceptions contribute to student difficulties in stoichiometry, through the planning and discussions in the meetings.

For the item on representations, Tendani selected the formula triangle, a symbolic representation in the pre-test. He explained how it could be used, which was confirmed in the first planning meeting where he discussed how he used it as a memory aid for his students. In the post-test, Tendani selected representation 1, a table that provides a list of analogous counting units to introduce the mole as a counting unit. In his response, he provided a comparison that gave macroscopic examples with submicroscopic examples. These examples included determining the number of eggs in a dozen and in a mole, the number of oranges in half a dozen and in half a mole. He ended his comparison with an example of how many atoms in two and a half dozen or in two and a half moles. He did not include any symbolic representations which is why he only scored developing TSPCK in his post-test. Tendani did not have the time to submit a completed CoRe so there is no evidence of how he applied these ideas, related to the different levels of representation, to teaching another concept.

Tendani provided a list of six steps that students needed to follow when having to solve problems related to limiting reagents, in the pre-test. In the post-test, he again provided a list of steps to follow and did the calculation to determine the limiting reagent. In his response, he only used symbolic representations and there was not an explicit identification of student errors. However, the strategy clearly acknowledged that the limiting reagent cannot be determined from the mass of a substance, but that the amount of each reactant had to be determined. Included in his response was an explanation that the balanced equation with molar ratios had to be used to identify the substance that will be used up in the reaction. By providing procedures in both the pre-test and post-test, Tendani's statement in the discussion meetings about teaching for the exams is validated. He provided the students with these step-by-step procedures so that they can at least attempt the questions and get some marks in the exams. Tendani's participation in the Learning Study added to his knowledge about the difficulties students have in stoichiometry that he will use to help them to do better in exams. He developed a deeper knowledge of why students struggle with stoichiometry and he wants to share this knowledge with colleagues in his school district. His belief, related to teaching so that students perform well in exams, was evident throughout his participation in the discussion meetings and in his desire to share his learning with his colleagues.

The vignette above provides a description of the changes in score for Tendani's pre-test and post-test, with supporting evidence drawn from the planning meeting, his pre-lesson interview and his video-SRI. The last vignette outlines Sizwe's story.

6.5.4. Sizwe's Story

The previous two vignettes provided detailed descriptions of how both Sipho's and Tendani's scores changed, or did not change through the qualitative analysis of the responses to the pre-test and post-test. In this vignette, the story of Sizwe's change in scores is outlined. In subsection 6.5.1, a detailed description of how the vignettes were compiled was provided. In this first subsection, Sizwe's instruments were used as an example, for describing how the sections of the vignette related to CSA and REP were compiled. Below is Sizwe's story.

Vignette Three: Sizwe's Story

Sizwe's epistemological beliefs are all instructive and, unlike his peers, he felt that he was not bound by work schedules before moving on to teach the next topic. He believes that time can always be made up by spending less time on topics that students do not have difficulties with. He believes that his role as a teacher is to develop students' understanding of science and its relevance to their everyday life. He believes that it is important to provide students with varied experiences, including practical work, to help them understand and explain scientific concepts. Sizwe felt that he has quite a bit of influence over encouraging student participation and was confident in his ability to implement teaching strategies. He did however feel that, in terms of classroom management, he had only some influence in ensuring that effective learning can take place in his classroom. Sizwe's participation in the PLC was for his own development, as a teacher and as a researcher completing his own research project. Completing the pre-test and post-test were a way for Sizwe to not only measure his progress but examine the progress of his colleagues for his research project.

In the pre-test, Sizwe selected mass, molar mass and volume as his big ideas. His reasoning mirrored the misconceptions students often had. He felt that mass was important in that it gave you an idea of the amount of substance, and molar mass related to the mass of substances in grams. For volume, he linked the idea to concentration in terms of one substance taking up space in another. His concept map provided a better understanding of how the mole was linked to the ideas of mass, molar mass and volume, but for Sizwe, the mole and amount of substance were not related. He viewed amount of substance as referring to the mass of a substance. Sizwe only considered stoichiometry important for its application of finding the mass of reactants and products in the pre-test. In the post-test, he selected the mole concept and concentration as big ideas, as the discussion in the planning meeting highlighted the link between amount of substance and concentration. He was also able to

think beyond just the practical application and considered the mole concept an important gate-keeping concept for developing understanding in other chemistry topics. He listed these topics to include electrochemistry, and applying it to the change in mass of the electrodes and chemical equilibrium, where the concept is needed to determine the number of moles at equilibrium to calculate the equilibrium constant.

In the pre-test, Sizwe selected the best response for the first item related to molar volume and selected the algorithmic response to the item relating to dissolving ten grams of three halides in an equal volume of water. His reasoning for the first LPK item was more detailed than the other two teachers as he related the mole to the number of particles. He however did not confront the misconception related to molar volume only being applicable to gases. His reasoning for the second LPK item related to the response including the relevant formula to calculate concentration. In the post-test, for the first item, he expanded on his explanation by focusing on the reasons in the response related to the phase of the substances. For the second item, he specifically confronted the misconception by stating the concentrations cannot be the same even though the salts were dissolved in the same volume of water since the number of moles was different. For the item WDT, in the pre-test, Sizwe provided reasons related to students' inability to balance equations for the difficulty they had with stoichiometric calculations and their inability to convert volume units when doing concentration. He however, did not consider the mole a difficult concept. In the post-test, he included more ideas, including the mole and Avogadro's number in addition to concentration and stoichiometric calculations. However, he did still not include any specific misconceptions related to student difficulties which was why he only moved from basic to developing TSPCK in WDT.

For Sizwe, integrating the three levels of representation was challenging and using the different levels of representation was not a common practice. He felt that in science, students were most familiar with the symbolic level. Through his participation in the Learning Study, he began to realise the importance of beginning with the macroscopic level, which was what learners were familiar with, things they could see, and then explain concepts by using submicroscopic representations. In the pre-test instrument, Sizwe liked the formula triangle as it provided students with an easy way to cope with calculations. In the post-test, however, he selected the multi-faceted representation of equal volumes of hydrogen gas and fluorine gas reacting to form hydrogen fluoride gas which had double the volume. In his explanation, he linked the three levels of representation and added another dimension by explaining how the macroscopic property of mass could be used to introduce students to calculating the number of moles. Therefore, his score improved from basic TSPCK to exemplary TSPCK in this item of the instrument. The use of the different levels of representation was also clearly evident in his CoRe for teaching concentration. He began with a macroscopic hands-on activity students could do: to taste the difference when dissolving increasing teaspoonfuls of sugar to water.

He also outlined a demonstration he would do in the CoRe and provided an example where he would integrate the three levels of representation, starting with the macroscopic, then moving to the microscopic and only then introducing the symbolic in calculations. In his second example, symbolic representations are brought in earlier with the use of the periodic table.

In the pre-test, Sizwe provided a very limited response to the CTS item. He first emphasised the need to convert from kilograms to grams and then provided the formula to convert from mass to number of moles, and also only used symbolic representations. He also stated that the number of moles had to be determined in order to know which reactant is the limiting reagent. In the post-test, his response was far more detailed. He provided a table that illustrated how the limiting reagent can be determined. Again his response was only limited to symbolic representations that included the table and calculations. He did however, clearly state the misconception related to mass for determining the limiting reagent and there was evidence of curricular saliency, in that he clearly provided the standard definition for the limiting reagent. Overall, Sizwe showed the greatest improvement and his participation in the Learning Study helped him develop a better understanding of how to use the three levels of representation together when teaching. One habit that was not broken, despite the emphasis in the discussion meetings by the researcher, was referring to the symbol for amount of substance as number of moles. Like Sipho, Sizwe also felt that time constraints would impact on how he would apply this in the classroom because of the lack of time to do practical work and deal with the macroscopic aspects of representations.

This subsection has provided a detailed description of Sizwe's learning as a vignette. The vignette outlines the changes of his scores in the TSPCK Instrument completed before the Learning Study as a pre-test, and after the Learning Study as a post-test. The last subsection pulls these three vignettes together and attempts to link the changes in scores, described in the three vignettes, to the discussions in the PLC.

6.6. Teacher Learning and Interactions in the PLC Meetings

In the previous section, the qualitative analysis of the responses to the three participating teachers' scores in the pre-test and post-test were described in the form of vignettes. In this section, this analysis will be discussed in terms of the 'TSPCK talk units' from the meetings of the PLC. Figure 6.18 provides a graphical representation of the changes in scores discussed in Section 6.2 and the TSPCK talk units across the five PLC activities discussed in Section 6.3.

The first bar graph in Figure 7.18 shows the changes in scores in the participating teachers' pre-test and post-test scores. The second bar graph shows the number of TSPCK talk units in each of the meetings. Since the teachers' participation was limited, the bar graph includes the talk units of the experts, because the engagement with the experts contributed to their opportunities to learn. This is done in order to show any links between the changes in score and the discussions in the meetings.

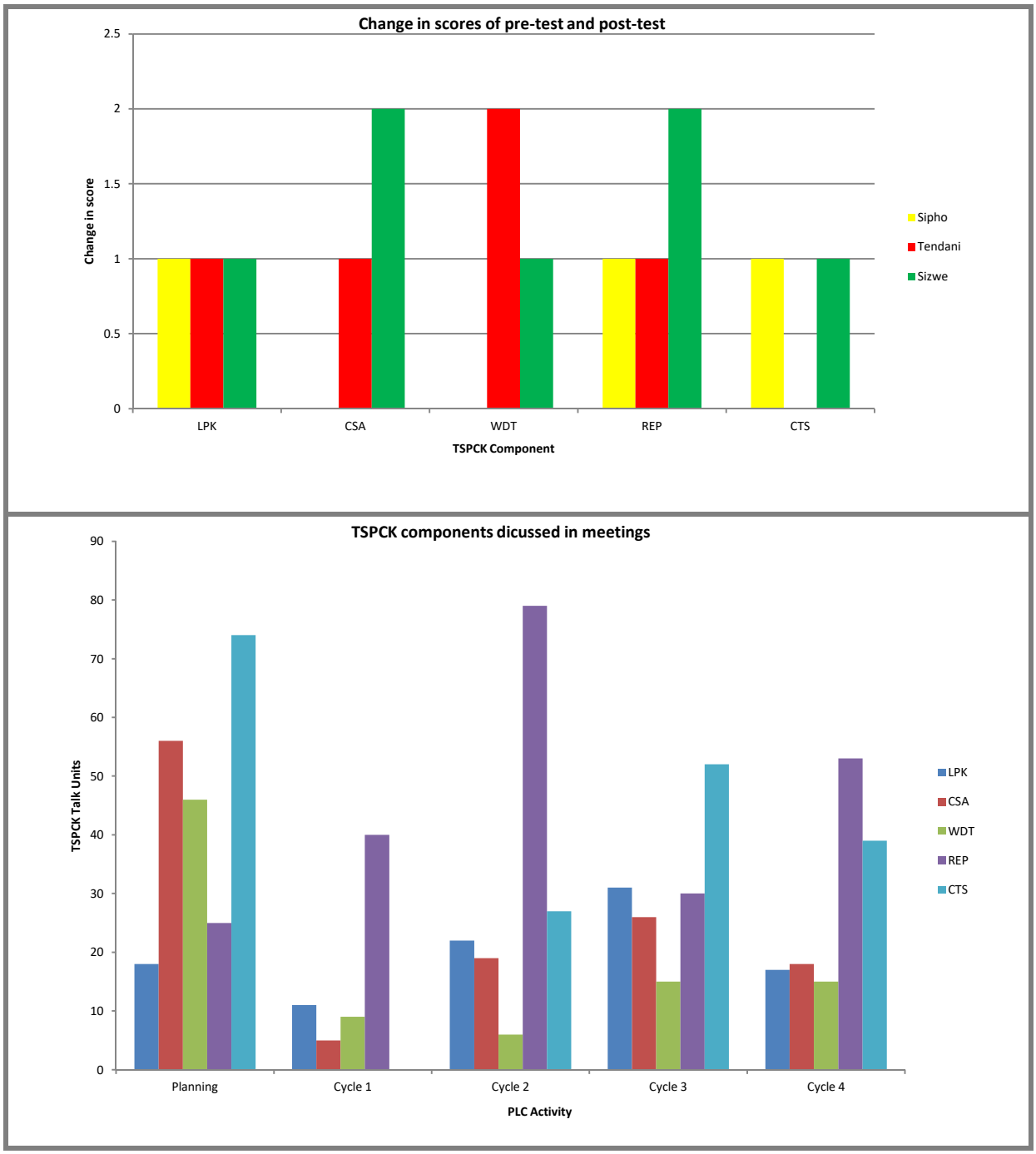


Figure 6.17: Bar graphs of change in pre-test and post-test scores and number of TSPCK talk units in the PLC activities

Firstly, it is worth noting that, in terms of the change in scores, there were no negative changes. The teachers' scores either improved or remained the same. Where the scores remained unchanged, there is no bar for that teacher in the first graph in Figure 6.17. As is evident in Figure 6.17, all three teachers' scores changed by 1 in the component LPK. The common misconceptions were discussed in the planning meeting when developing the CoRe for the big idea related to the mole. Variations of the misconceptions tested in the CK Instrument were used in the diagnostic tests the students being taught wrote before and after the lesson. For this reason, LPK was discussed in each meeting as seen in the bar graph of TSPCK talk units (see Figure 6.17), as we engaged in interrogating the students' performance in the diagnostic test. According to Brodie (2014), when teachers engage in discussions related to identifying, interpreting and engaging with student errors, in this case misconceptions, this results in a deepening of teachers' thinking related to student errors. This is clearly evident in the vignettes for all three teachers in their response to the LPK items. The changes in scores were due to their reasoning related to the selection of their answers. In all cases, when compared with the responses in the pre-test, the level of reasoning deepened. In the pre-test, the teachers typically only provided standardised knowledge in their response. In the post-test, they first explicitly stated what the misconception was and confronted the misconception in their reasoning. Not only did they provide standardised knowledge but also expanded on this knowledge.

In the item CSA, only Tendani and Sizwe had a change in scores (see Figure 6.17). However, Tendani's change in score was not related to his selection of big ideas. The item relating to CSA consists of four sub-items. These include identifying the big ideas, indicating how the big ideas are linked by constructing a concept map, identifying important pre-concepts that need to be taught before teaching the various big ideas related to stoichiometry and the importance of knowing the big idea. From the vignettes, it is evident that Sipho and Tendani, in both the pre-test and post-test, only selected the mole concept as a big idea. Sizwe, who initially only identified subordinate concepts, such as mass and molar mass, as big ideas in the pre-test, correctly identified two big ideas in the post-test. The component of CSA was discussed extensively in the planning meeting (see Figure 6.17) and much of this discussion related to the relevance of teaching stoichiometry. The vignettes, particularly in the case of Tendani and Sizwe highlight how they discussed the application of the mole concept in industry and its scaffolding for other chemistry topics. The fact that the participants still

struggled to identify the other big ideas is supported by claims that selecting big ideas is challenging (Loughran *et al.*, 2012; I. Mitchell *et al.*, 2017). It has been also been reported that teachers require input on conceptual understanding for meaningful engagement about selecting big ideas (Rollnick & Mavhunga, 2015). This is evident in that all three teachers selected the mole as a big idea because of the engagement in the Learning Study. In the discussion meetings, CSA was only discussed in terms of the big idea related to the mole and Sipho, as is evident in his vignette, felt this overshadowed their thinking when completing the TSPCK Instrument as a post-test. Since there was no meaningful engagement in the other big ideas other than in the planning meeting, with the exception of Sizwe, they therefore only selected the mole because of the level of engagement with this big idea in the discussion meetings.

The improvement in the component WDT can be attributed to debates in the planning meeting related to what constituted learner prior knowledge and the planning of the activities taught around aspects of why stoichiometry is difficult. In the planning meeting, there are approximately 50 talk units for the component WDT (see Figure 6.17). This component was discussed in all the cycles of the Learning Study as all the activities were designed around this TSPCK component. Tendani's score showed the greatest improvement in this component and Sizwe's score changed by 1 (see Figure 6.17). As is evident in Sizwe's vignette, he included the mole concept as an aspect of WDT in his post-test. As with LPK, the component WDT relates to what students find difficult to understand and also focuses on learner errors. The explicit discussions around this component deepened teachers' thinking and can account for the change in scores (Brodie, 2014). In Tendani's case, it would appear that his epistemological belief as an instructive teacher teaching for exams amplified this knowledge component in his learning (Gess-Newsome, 2015).

Figure 6.17 also indicates that the REP item showed an improvement in score for all three teachers. This component was discussed extensively in all the PLC activities and dominated the discussion when talking about TSPCK. This is evident by the number of TSPCK talk units in cycle 1, cycle 2 and cycle 4 of the PLC activities. In Sizwe's vignette, the challenges he had with using representations when teaching the lesson are outlined, but through the process he was able to work through these, as is evident in his CoRe in which he shows how he would integrate the three levels of REP when teaching concentration (see Figure 6.15). Sipho's improvement since he selected the same representation in his pre-test and post-test as

shown in his vignette was related to his integration of the three levels, particularly in teaching stoichiometry. Tendani's vignette highlights how he integrated symbolic and macroscopic representations that accounts for his increase in score in the REP item. These improvements are consistent with other studies that have found that participation in a Learning Study enhances teachers' PCK development (Nilsson, 2014).

Finally, in terms of the CTS item, both Sipho and Sizwe improved but Tendani's score was static (see Figure 6.17). This was despite the fact that there were over 70 talk units related to CTS in the planning meeting (see Figure 6.17). The difficulty the teachers had with this component is evident in that, when discussing the lesson after the first cycle, there were no talk units for CTS in the cycle 1 discussion meeting. As time progressed, talk about the CTS component increased substantially. Despite this, however, both Sipho's and Sizwe's change of score were attributed to the integration of components, like explicitly identifying the student error and sequencing of ideas rather than using the three levels of representation in their teaching strategy. The lack of substantial integration of all the other components of TSPCK in the CTS item, could be attributed to the teachers' epistemological beliefs related to teaching science, since as experienced science teachers are less likely to change these beliefs (Luft & Roehrig, 2007). In Tendani's case, as is evident in his vignette, he gave himself a perfect score for the items related to his self efficacy in implementing instructional strategies. His high self efficacy beliefs are a possible indication of the ceiling effect and he therefore does not think he needs to improve his teaching strategies (Fives & Buehl, 2010).

In all three cases, the lack of substantial improvement in the CTS item could also be attributed to time restraints, related to curricular demands, and contextual factors, such as resource availability. All three teachers were involved in the Learning Study for their research projects and the lesson was taught as a revision lesson outside of normal school hours. The engagement with conceptual teaching strategies in this lesson, although valuable for the teachers in terms of learning, has no practical value outside of this study and in their classrooms. This is evident in what they said in the SRIs or the exit discussions. Examples of what the teachers said are provided below.

Tendani saw the engagement as valuable on a personal level but impractical to implement in reality because of curricular restraints and completing the syllabus.

Tendani (line 20): *Personally all the activities that we did in the lesson were very necessary. But when I was looking now at the time factor, they won't fit into our thirty minute periods. Things should be taught according to our schedules in a thirty minute period. So, ja, I'm saying, they are very good activities that we planned for that lesson. They are very good. But if we teach like this we won't finish our schedules.*

This was reiterated by Sizwe in the exit discussion. He felt that, in terms of the school year, the length of periods and assessment, there were just too many demands to be able to implement these types of teaching strategies.

Sizwe (line 30): *We have time constraints in the schools. It's good for them to do practical activities, but we have got challenges in terms of very short terms, schooling terms, nine weeks. In those nine weeks we should teach, test and mark, report, and all that.*

For Sipho, the restraints were related more to the contexts within the type of school at which he was teaching and the lack of resources.

Sipho (line 7 & 73): *I've been teaching in schools that are underprivileged, so the issue of resources and the kinds of learners that I've been teaching impacts a lot on my teaching methods. I think also the overcrowding. It's a serious challenge. If you want to do an experiment with a group of fifty learners…unless maybe it's a demonstration, otherwise it's difficult to group them so that maybe they can utilise the apparatus fully. So we end up not doing these practical activities, and just teach them theoretically.*

The above quotes highlight how the knowledge developed from the PLC in terms of instructional strategies for teaching the mole concept was still filtered through the lens of the teacher when answering the CTS item on limiting reagents (Gess-Newsome, 2015). The Learning Study provided the teachers with an opportunity for professional development, but this knowledge can be modified, embraced or even rejected as was the case with Tendani. As Gess-Newsome (2015) highlights, contextual variables influence how teachers use knowledge and this is evident in the teaching strategies described by both Sipho and Sizwe in the post-test since they do not move beyond the use of symbolic representations. In Tendani's case, his orientation to teaching which is more didactic as he teaches for exams, acted as a filter in that he did not apply the knowledge he gained to his teaching strategy when answering the CTS item in the post-test (Gess-Newsome, 2015). If beliefs can filter and

amplify teacher knowledge gained through participation in a PLC, how then was the enactment of the lesson impacted? This will be looked at in the chapter that follow.

6.7. Summary

In this chapter, the development of teachers' TSPCK through participation in a PLC has been investigated. Since this study is a mixed methods study, the change in scores in the pre-test and post-test were first analysed quantitatively. This was done by stacking the post-test scores and treating the post-test as though it was written by new people, since the assumption was they were changed through the intervention. The Rasch analysis has shown that after the Learning Study, the three teachers improved their ranking. All three teachers were placed above the median score of the instrument in the second Rasch analysis and their participation in the Learning Study contributed to this improvement. A *t-test* of the mean scores for the items and persons was conducted to test the assumption that the post-test scores could be treated as new people drawn from the same population of experienced teachers. This assumption was shown to be valid as there was no significant difference between these means for the sample of thirty-one teachers and the sample of thirty-four teachers.

The qualitative data from the PLC meetings was also analysed to gauge the extent to which the specialised knowledge, namely TSPCK, as a component of the TPK&S model, was part of the conversations in the Learning Study. The analysis indicates that the specialised knowledge comprised a substantial portion of the talk units in the PLC activities. Although the teachers' participation in terms of talk units ranged between thirteen and nineteen percent in comparison to the experts, the engagement still provided opportunities for learning. The quantitative analysis therefore indicates that the teachers' TSPCK was developed through participation in these discussions in the Learning Study.

To account for the change in scores, a qualitative analysis of each teacher's pre-test and post-test was conducted. This was captured in the form of vignettes. The vignettes highlight in which components of TSPCK the teachers improved, and this was supported by evidence from interviews and the discussions of the PLC. There is evidence that the teachers' learning was either amplified or filtered, based on their beliefs and contextual factors. Finally, evidence from the vignettes, the changes in scores and the quantification of the discussion related to TSPCK as talk units, was integrated to account for the changes in scores. This chapter has only focused on the discussion and planning meetings. It was found that the

experts provided more input in terms of the discussions and yet the participating teachers still improved their TSPCK scores. What has not been considered is the actual teaching of the lesson, the enacted TSPCK based on the collective TSPCK evident in the PLC and how this contributed to their learning and impacted their classroom enactment of the lesson. The next chapter will describe the product of the PLC discussions, the lesson. The lesson was enacted by each teacher to examine how the collective TSPCK evident in the PLC is translated into classroom enactment when teaching.

CHAPTER SEVEN

The Quality of Teachers' Enacted TSPCK in the Classroom

This chapter aims at providing an overview of the impact of the Learning Study on the enacted TSPCK in the classroom when teaching the lesson planned using the collective TSPCK of the Professional Learning Community. This chapter, therefore, informs part of the third and final sub-question of the research question. In order to do this, an analysis of the video recorded lessons for each participant was conducted to identify TSPCK episodes, which are defined in the first section of this chapter. These TSPCK episodes are described and mapped, in terms of the components of TSPCK, to determine the extent to which there is an interaction of the components. The TSPCK episodes were then scored with a TSPCK classroom rubric to provide a means to evaluate the TSPCK in practice. Secondly, in order to compare and discuss the extent to which the collective TSPCK of the PLC members conducting a Learning Study had on the teachers' enacted TSPCK, a comparison is made of three teachers' enacted TSPCK teaching in the same school who were not involved in the collaboration. This comparison aims to investigate any differences in the numbers and quality of the TSPCK episodes with those participating in the Learning Study.

7.1. Introduction

In order to investigate the extent to which the collective TSPCK evident in a Professional Learning Community participating in a Learning Study is enacted in the classroom, there is a need to acknowledge that teaching, although it appears deceptively simple, is complex (Grossman, Hammerness, & McDonald, 2009). Within the classroom setting, moving from the planned instructional activities in a lesson plan to the enacted lesson, especially in terms of the components of TSPCK is also complex (van der Merwe, 2018). With experienced teachers, there is an added layer of complexity. Experienced teachers work off mentally stored scripts that have been built up gradually over time from previously planned lessons, which they have implemented, reflected on and improved over the years (Stender *et al.*, 2017). During the Learning Study, the three participating teachers' enactment of the planned lesson, developed collaboratively in a PLC by explicitly engaging with the TSPCK components, was video-recorded. The video-recorded lesson, enacted by each teacher, was analysed through an in-depth analysis of TSPCK components, in terms of the interaction of

the components, the structural sequence in which the interactions occurred and the interconnectedness of the components (Mavhunga & van der Merwe, 2017; Park & Chen, 2012).

This chapter aims to investigate to what extent the TSPCK component interactions in the enacted lesson about the mole concept in stoichiometry are influenced by the collaborative interactions in the PLC. The in-depth analysis of the TSPCK components is therefore compared with an equivalent comparison group of three teachers working in the same school but who do not work collaboratively and were not exposed to any discussions about the components of TSPCK. The teachers in this comparison group taught lessons, covering the same content as the Learning Study group of teachers. To compare the TSPCK component interactions in such varied enactments of lessons, the teaching contexts in which the interactions of TSPCK components emerged (Mavhunga, 2015) were drawn from an aspect of general pedagogical knowledge, the lesson elements for planning an effective lesson (Hunter & Russell, 1976). The teaching contexts for interacting TSPCK components related to the lesson element on the teaching of concepts, was further categorised based on the important relationships between the mass of substances, the volume of gases and the number of particles encompassed in the big idea related to the amount of substance and its SI unit, the mole (Furio *et al.*, 2000). This was done to determine the extent to which the interactions in the PLC contribute to the number and quality of interacting TSPCK components in teaching the mole concept.

Before discussing the findings there is a need to clarify what is meant, firstly by quality, and secondly by interactions in the Professional Learning Community. In this chapter the quality of interacting TSPCK components refers to the number of TSPCK components visible in a teaching segment and the interconnectedness between these components in the enacted lesson. The interactions in the PLC refer specifically to the teams' discussions related to the planning, reflection on the lesson, student performance in the diagnostic questions and improving the lesson. In the previous chapter it was shown that a large portion of these interactions centered around TSPCK and the components of TSPCK (see Figure 6.8). Chapter 5 outlined the activities of the PLC and highlighted that the discussions focused on planning conceptual teaching strategies based on student difficulties or misconceptions which were captured in the adapted CoRe and the lesson plan. This chapter therefore seeks to establish to what extent the collective PCK of the PLC members for the topic of stoichiometry, used in

the planning and refinement of the lesson, impacted on the enacted PCK when teaching the lesson.

7.2. Lesson Elements and TSPCK Episodes in the Lessons

A key feature of a Learning Study is that the lesson is revised and changes are made to improve the lesson (Pang & Marton, 2003). As a result, the instructional activities change, in order to effect improvements in student performance. In order to investigate if the TSPCK component interactions discussed in the PLC were enacted in practice, TSPCK episodes needed to be identified through an in-depth analysis of each lesson for each teacher in the Learning Study group. Additionally, in order to effectively describe the extent to which interactions in the PLC impacted on the enactment of the lesson, the lessons conducted by the three teachers participating in the Learning Study were compared with three teachers not participating in the Learning Study. These teachers were selected from those that had completed the TSPCK Instrument for validation (see Appendix 8) and worked in the same school. The equivalence of these two groups of teachers was outlined in Section 3.5.4 of Chapter 3. The lessons of the comparison group were initially observed in order to gauge the baseline quality of enacted PCK, for teaching stoichiometry. This was done as a means to ascertain the extent to which measured TSPCK, or cPCK matched enacted TSPCK, or ePCK. However, the observations proved useful as a comparison to determine the extent to which the interactions in the PLC impacted on the enacted TSPCK of the teachers participating in the Learning Study. Such a comparison required, firstly that the two groups were similar (White & Sabarwal, 2014). Secondly, the lessons from both groups needed to be analysed in a way that was comparable in order to evaluate the effectiveness of participating in a Learning Study on classroom enactment. Both of these aspects are discussed in this subsection.

7.2.1. The Equivalence of the Two Groups of Teachers

This study aimed to investigate the impact a Learning Study as a professional learning activity had on enacted TSPCK when the collaboratively planned lesson was drawn from the collective TSPCK of the PLC. Ideally, as with the development of the teachers' TSPCK described in the previous chapter, the impact on enacted TSPCK could be better described by comparing the teachers' lesson on the mole concept before participating in the Learning Study. This was, however, not practical for a number of reasons which were outlined in

Chapter 3. However, as outlined in Chapter 3, in order to compare the impact of the Learning Study as an intervention on teachers' enacted TSPCK, the comparison group needed to be similar to the intervention group (White & Sabarwal, 2014). In order to compare the impact of the Learning Study on teachers' enacted TSPCK, the Learning Study group was compared with comparison group of teachers. The two groups shared similar features (see Section 3.5.4), which is important when investigating the impact of an intervention (White & Sabarwal, 2014). The key element that distinguished these two groups of teachers was the extent of their collaboration. The Learning Study group were part of a PLC that planned a lesson collaboratively whereas the comparison group planned and worked independently, despite teaching the same grade in the same school. The next subsection provides an outline of the analytical frameworks, used to analyse the enacted lessons.

7.2.2. Lesson Elements in the Different Enacted Lessons

In Chapter 3, the equivalence of two groups, the Learning Study group and the comparison group of teachers was described. The equivalence between the two groups of teachers is important in order to be able to investigate the impact of interactions in a PLC in the enacted lessons of the teachers involved in a Learning Study. The lesson of the Learning Study, the development of which was described in Chapter 5, was developed as a revision lesson explicitly using the components of TSPCK. The lesson consisted of four activities conducted over two sessions on the same day, whereas the lessons of the comparison group were conducted during normal school hours, in which the periods were forty minutes long. The second cycle of the Learning Study, taught by Sipho was two hundred minutes in length and with refinement, by the time Sizwe taught the lesson, it was one hundred and fifty minutes long. For the comparison group, four to five lessons were observed, based on the time it took for the teacher to cover the content related to teaching the mole. Therefore the length of the observations ranged from one hundred and sixty to two hundred minutes. However, the common thread in both groups was the teaching of the big idea related to the mole. For the Learning Study group, this idea was the object of learning around which the lesson was collaboratively planned (see Chapter 5). For the comparison group, the big idea was discussed and the subordinate concepts were outlined individually with each teacher for them to do their own planning. This was done with the comparison group because the analysis of the TSPCK instruments described in Chapter 4 highlighted that teachers had difficulty identifying big ideas and in the CAPS curriculum, molar volume is not sequenced with the

content related to understanding the mole. Other than this input, which was related to framing the big ideas for the instrument design (see Appendix 6), the comparison group had no access to any of the information generated from the Learning Study. The lessons were therefore highly varied; even amongst the teachers in the Learning Study in which the components of TSPCK were explicitly used in the planning of the lesson.

The TSPCK model served as the main analytical tool as TSPCK components were identified in teaching segments in the enacted lessons. This was done through an in-depth analysis of the lessons and is described in Chapter 3. However, in order to investigate the natural interactions of TSPCK components from the collaboratively planned collective TSPCK of the PLC to enacted TSPCK in the Learning Study lessons, and compare this with the comparison group's enacted TSPCK, teaching contexts needed to be identified (Mavhunga, 2015). The dilemma faced was that the lessons in the Learning Study were planned around hands-on practical activities and group work, and were learner-centred, whereas the lessons from the comparison group were more traditional transmission type lessons. Therefore, a way to look at the enacted TSPCK of the teachers as a generic instructional process for effective teaching was required (Wolfe, 1987). The lessons were also therefore analysed in order to identify the generic instructional processes or instructional elements in the lessons and establish the context in which the natural interactions of TSPCK components emerged. The instructional elements selected were drawn from the seven elements to be considered when planning an effective lesson (Hunter & Russell, 1976). These elements include the anticipatory set, objectives, input, checking understanding, guided practice, independent practice and closure. Independent practice refers to providing students with homework to practice what has been taught in a lesson and was not used in this analysis. A detailed description of how these elements were used as the teaching contexts, in which the natural interactions of the TSPCK emerged, is provided in Chapter 3. Assigning the teaching segments, with interacting TSPCK episodes, to these teaching contexts was done so that the three teachers involved in the Learning Study, and the three teachers that formed part of the comparison group could be compared to determine the impact of working collaboratively on enacted TSPCK. A working definition for these teaching segments or TSPCK episodes is provided in the sub-section that follows.

7.2.3. Defining TSPCK Episodes

Identifying TSPCK episodes was done through an in-depth analysis of the video-recorded lessons. For the purposes of this study, an episode was identified based on the definition provided by Park and Chen (2012) and modified for TSPCK (Mavhunga, 2015; van der Merwe, 2018) as a teacher task segment, in which two or more TSPCK components are displayed and interacting. The identified teaching tasks in a teaching segment, were labelled according to six of the instructional elements for planning a lesson mentioned in the previous subsection (Hunter & Russell, 1976). The input element, which relates to teaching concepts, was further categorised into whether the input related to the three important relationships between amount and mass, amount and number of particles, and amount and molar volume described by Furio *et al.* (2000) as central to developing students' understanding of the mole concept. The TSPCK episodes were then described in detail (refer to Appendix 17). The description included the aspects outlined below, which was guided by the work done by Mavhunga (2015). These aspects included: (i) what the teacher had done in the lesson, (ii) what TSPCK components are at play in the segment, and (iii) the emergence of the components in an interaction or the nature of the sequence of the TSPCK components. The sequence and/or emergence of the components were then mapped visually in a TSPCK episode map. The TSPCK episodes can therefore be as short as a few minutes, if the teacher is responding to a student question, or be a single activity within the lesson. Two raters were involved in identification, developing the descriptions and TSPCK episode maps. The section that follows describes how the TSPCK episodes were identified and scored using the TSPCK enactment rubric (Miheso & Mavhunga, 2018).

7.3. Identifying and Scoring the TSPCK Episodes

According to Gess-Newsome (2015), classroom enactment is the location of PCK since it is here that the teachers, in an attempt to carry out their instructional plans need to monitor student understanding and adjust instruction. In this study, the instructional plan was guided by the explicit inclusion of the components of TSPCK in planning the lesson by drawing on the collective TSPCK of the members of the PLC as described in Chapter 5. However, the extent to which these components enacted in the lesson, considering the complexity associated with moving from planning to the enacted lesson (Mavhunga & van der Merwe, 2017), needed to be captured. Since successful classroom enactment depends on the

integration of the components of TSPCK in coherent interactions (Aydin, Demirdogen, Nur Akin, Uzuntiryaki-Kondakci, & Tarkin, 2015), when capturing the TSPCK episodes, the focus of the analysis needed to capture these interactions. The extent to which the critical engagement and discussion of the lesson in terms of the TSPCK components by the team members contributed to the integration of TSPCK components in the enacted lesson can therefore provide evidence of the impact of a Learning Study on enacted TSPCK in the classroom. Investigating the integration of the TSPCK components in the enacted lesson when compared alongside the lessons in the comparison group can reinforce any evidence of the impact of the Learning Study on improving classroom enactment when teaching stoichiometry. This section therefore provides a brief summary of the analysis of the video-recorded lesson of the Learning Study group and comparison group, which was described in detail in Chapter 3.

7.3.1. How TSPCK Episodes were identified from In-depth Analysis of Lessons

In Chapter 3, a detailed outline of how the nature and integration of the TSPCK components in the enacted lessons were captured through an in-depth analysis of the video-recorded lessons using the approach described by Park and Chen (2012) was provided. This included:

1) How the descriptions of teaching segments were developed from the video-recorded lessons and complemented from pre-lesson interviews and video-stimulated recall interviews.
2) How the TSPCK components were identified, based on definitions of each component in the descriptions of the teaching segments.
3) How the TSPCK components interacted in the teaching segments and the nature of these interactions.

The TSPCK episodes, as defined in the previous section of this chapter, required at least two TSPCK components to be evident in the teaching segment.

7.3.2. Developing the TSPCK Maps from Summarised Descriptions

From these summarised descriptions, TSPCK episode maps, described as analytical devices (Park & Chen, 2012), were developed to illustrate the number of TSPCK components and their interaction per participant. The TSPCK components were included only once if they appeared in an episode and the teacher came back to this component. However, if a TSPCK

component was repeated based on the different levels of sophistication, such as different levels of representation, or different aspects of learner prior knowledge such as a misconception or what had already been learnt, and curricular saliency such as providing standardised knowledge, or the application of a concept to another topic these components were included more than once in the map. Appendix 17 provides the operational definitions for each TSPCK component on which the decision to include a component more than once in a TSPCK episode map was made. The teaching context in which the interaction of TSPCK components emerged, referred to as the platform in the TSPCK episode map (Mavhunga, 2015), was based on research-validated lesson elements for effective lesson planning (Hunter & Russell, 1976). The reason for this decision was outlined in the previous section. For the lesson element related to input, the aspects of the big idea related to the mole were also included in the platform (see Chapter 3). These included: (i) the mole as the SI unit for amount of substance and the relationship between amount and mass, (ii) the mole as a counting unit of elementary particles, and (iii) molar volume were also included in the platform because of the importance of these relationships in helping students understand the mole concept (Furio *et al.*, 2000). The TSPCK episodes were then scored using the enacted TSPCK rubric which is discussed in the sub-section that follows.

7.3.3. Scoring the TSPCK Episodes using a Rubric for Enacted TSPCK

This chapter, in part, aims to determine to what extent the interactions in the PLC related to the collective TSPCK of the team impacted on enacted TSPCK in the classroom. This is done by comparing the extent to which the TSPCK components interact in the lesson with the comparison group and allocating an ordinal score to allow comparison. This was done by using the classroom enactment rubric that was designed using TSPCK as a theoretical framework and developed and validated in a study conducted by Miheso and Mavhunga (2018). For the purposes of this study, the enacted TSPCK rubric was used as a rating scale to capture information similar to a Likert scale (Dawes, 2008). However, unlike a Likert scale, the rubric was not used to assign ordinal scores to subjective responses such as attitudes or opinions (Wu, 2007). According to Wu (2007), assigning integer scores to such subjective categories is often criticised as being unrealistic since they do not reflect realistic differences. However, in this case, the categorisation does allow for an ordinal scale to place the TSPCK episodes in rank order (Lammers & Badia, 2004). The TSPCK episodes are ranked based on

the number of interacting TSPCK components visible in the map. This sub-section will briefly describe the rubric used, and examples of TSPCK maps with varying quality in terms of the number of interacting components, and how the rubric was used to score the TSPCK episode maps and provided in Appendix 17.

The Enacted TSPCK Rubric

The enacted TSPCK rubric was conceptualised and its design guided by the TSPCK theoretical framework (Miheso & Mavhunga, 2018). Therefore, its use in this study, which was also guided by the TSPCK theoretical framework, was justified. The rubric was designed and validated specifically to categorise TSPCK episodes into categories of TSPCK quality based on the number of interacting components. The rubric is shown in Figure 7.1 on the next page.

The rubric is a set of criteria that are specifically used to distinguish the quality of the TSPCK episodes in terms of the number of TSPCK components and the interaction amongst these components (Miheso & Mavhunga, 2018). The classroom enacted TSPCK rubric consists of three categories, with 'Type 1' indicating basic TSPCK enactment. The criteria for scoring a TSPCK episode as basic include the presence of two TSPCK components with one interaction between the components (see Figure 7.1). The second category, 'Type 2' includes criteria for a higher quality TSPCK episode which is described as proficient TSPCK. These criteria include the TSPCK episode being a three-component episode with two interactions. The components could be three different components, or consist of three TPCK components, with one component being repeated in the interaction. One of the components may be implicitly addressed. Finally, a sophisticated TSPCK episode, labelled as 'Type 3' (see Figure 7.1) includes four or more TSPCK components interacting. The TSPCK episodes scored as 'Type 3' could be episodes that contain four different TSPCK components interacting, or three different TSPCK components with one or more of the components being repeated. However, all episodes must be at least four-component episodes in which the components interact and are explicitly distinguishable.

Type 1: Simple TSPCK Episode	Type 2: Proficient TSPCK Episode	Type 3: Sophisticated TSPCK Episode
• Evidence of two different TSPCK components interacting evidently and distinguishably in a specific teacher task segment • The TSPCK component interactions maybe interwoven or have a linear sequence structural formation. • Both components work together to support an explanation of a single or a pair of concepts that are related	• Evidence of three different TSPCK components interacting evidently and distinguishably in a specific teacher task segment • The three components interacting are clearly, explicitly all being used at a single/one dimensional level. **OR** • Evidence of three different TSPCK components interacting, evidently, and distinguishably in a specific teacher task segment, but one component repeating and bringing a different level of explanation that complements the initial emergence • The three components work together to support an explanation of a single or a pair of concepts that are related	• Evidence of four different TSPCK components interact evidently and distinguishably in a specific teacher task segment **OR** • Evidence of four TSP components interact evidently and distinguishably in a specific teacher task segment, with one of components repeate more than once or o of the components bringing different le of sophistication (e.g representations use macro, symbolic and submicroscopic leve • TSPCK component interactions maybe interwoven or have linear sequence structural formation both. • All the TSPCK components work together to support explanation of a sing or a pair of concepts that are related

Figure 7.1: The TSPCK rubric with criteria for describing the quality of TSPCK episodes seen in enacted TSPCK in the classroom

Overview of the TSPCK Episode Profiles of the Participants

The results of scoring process using the rubric are summarised below in Table 7.1 as TSPCK in action profiles (refer to Appendix 17 for examples of the different categories of TSPCK episodes). The TSPCK action profile provides an overview of the total number of types of TSPCK episodes as categorised by the TSPCK rubric.

Table 7.1: TSPCK Profiles of the teachers in the Learning Study group and the Comparison Group

Participants in the Learning Study		Comparison Group	
Name	**TSPCK Profile**	**Name**	**TSPCK Profile**
Sipho	Simple x 0 Proficient x 7 Sophisticated x 28	Janet	Simple x 6 Proficient x 14 Sophisticated x 3
Tendani	Simple x 3 Proficient x 16 Sophisticated x 10	Christine	Simple x 12 Proficient x 16 Sophisticated x 3
Sizwe	Simple x 4 Proficient x 17 Sophisticated x 14	Hendrick	Simple x 10 Proficient x 9 Sophisticated x 11

The TSPCK in action profiles shown in Table 7.1 at a glance provides the number of different types of TSPCK episodes identified, mapped and scored using the TSPCK rubric. Examples of the different types of TSPCK episodes from the TSPCK action profiles are provided in Appendix 17. These descriptions in Appendix 17 provide an indication of the quality and nature of the interactions by contrasting episodes from the teachers in the Learning Study group and the comparison group. In the next section, the results of the analysis and scoring of the TSPCK episodes of both the Learning Study group and the comparison group are described in a more quantitative way to expand on the TSPCK profile in action for the two groups of teachers. This is done in order to gain an insight into the impact of the Learning Study on the enacted TSPCK of teachers in the classroom.

7.4. Overview Analysis of the Number and Quality of TSPCK Episodes

The enacted TSPCK rubric developed by Miheso and Mavhunga (2018) served as a useful tool that provided an overview of the participants' quality of the interactions in their TSPCK episodes identified on a rating scale of 1 to 3. Three of these teachers, the Learning Study group, enacted a single lesson in two sessions conducted in one day, with three distinct aspects related to the big idea of the mole concept. The three teachers from the comparison group, all teaching the same grade at the same school, taught four to five forty minute periods around the same three aspects of the big idea related to the mole. Since the two sessions of the Learning Study group were not divided into equal time slots, it was not possible to make a comparison in terms of length of the lessons or the sessions. The key difference between these two groups of teachers is that the lesson structure for the Learning Study group emanated from the planning and discussion meetings (see Chapter 5), whereas for the

comparison group, the lesson structure was individually generated from their experience, or lesson scripts they draw from memory when teaching.

In Chapter 3, the equivalence of the two groups in terms of TSPCK and CK scores in the instruments, years of teaching experience and the scope of the content taught was outlined. The two groups were similar with the exception that the one group planned a lesson collaboratively in a Learning Study. In order to compare these very different lessons, Madeline Hunter's elements of an effective lesson (Hunter & Russell, 1976) was used. Firstly, an analytical framework for analysing the TSPCK episodes, identified, described and mapped in the lessons. Secondly, since the lesson elements represent tasks in a lesson, completed in a certain period of time, they provided a way to define the sessions for both the Learning Study group and the comparison group. Each lesson element therefore represents a session in teaching the mole concept. These sessions include introducing the mole concept, teaching the different concepts that go into helping students develop an understanding of the mole concept, guiding students in solving problems related to the mole concept, summarising and checking student understanding about the mole concept and bringing the lesson to closure.

In this section, the number and quality of the TSPCK episodes are analysed and statistically compared to determine to what extent participation in a Learning Study impacted on enacted TSPCK in the classroom. This will be done by firstly describing the differences and similarities in terms of the number of the TSPCK episodes in each session of the lesson, the number of different quality categories of TSPCK episodes (Miheso & Mavhunga, 2018) and the number of TSPCK episodes in the lesson elements of an effectively planned lesson (Hunter & Russell, 1976). Secondly, the connectedness of the TSPCK components will be mapped to provide an overview of the quality of episodes when considered together. Finally, the average scores per lesson element of the Learning Study group and the comparison group will be described.

7.4.1. The Number and Percentage of TSPCK Episodes

From the in-depth analysis, the TSPCK episodes were captured on an *excel spreadsheet* in which the type of TSPCK episodes were captured (see Appendix 20). These were tallied in order to capture the number of basic TSPCK episodes, proficient TSPCK episodes and sophisticated TSPCK episodes. The total number of TSPCK episodes for the Learning Study

group and the comparison group are shown in Table 7.2. The total number of episodes per quality categories as categorised by the TSPCK rubric (Miheso & Mavhunga, 2018) are recorded per lesson element (Hunter & Russell, 1976). The results for the Learning Study group are recorded in the first half of the table, with the results for the comparison group in the second half of the table. The total number of episodes is also included in the last row of each part of Table 7.2 on the next page.

Total Number of TSPCK Episodes in the Lessons

In the last row of each part of Table 7.2, for both the Learning Study group and the comparison group, the total number of episodes from the observed lesson(s) is recorded.

Sipho and Sizwe, who were part of the Learning Study group, had more TSPCK episodes in their eight sessions, whereas Janet, who was part of the comparison group, had the fewest TSPCK episodes in her eight sessions. Hendrick and Christine, who were part of the comparison group, had more episodes in their eight sessions than Tendani, who was in the Learning Study group. Overall, with the exception of Tendani's lesson, the teachers from the Learning Study group had more TSPCK episodes in their lessons than those of the comparison group. The percentage of TSPCK episodes per quality category is described below to understand the trends in the number of TSPCK episodes per quality category.

Total Percentage of TSPCK Episodes per Quality Category

Table 7.2 also shows the percentage of TSPCK episodes per quality category, as determined with the enacted TSPCK rubric.

The percentage of 'type 1' or basic TSPCK episodes observed in the teachers from the Learning Study group when compared to the teachers of the comparison group is much lower. In Tendani's lesson and Sizwe's lesson, there are only 10% and 11% basic TSPCK episodes respectively whereas the teachers in the comparison group had between 26% to 39% basic TSPCK episodes. Sipho had the lowest percentage of proficient TSPCK episodes at 20% and the highest percentage sophisticated TSPCK episodes at 80%. With the exception of Tendani in the Learning Study group who had only 35% sophisticated TSPCK episodes, the other teachers in the Learning Study group had a higher percentage of sophisticated TSPCK episodes in their lessons when compared to the comparison group.

Table 7.2: A summary of TSPCK episodes in the Learning Study group and comparison group respectively

Lesson Element (Represents a teaching session related to the mole concept in each lesson)	Learning Study Group											
	Sipho				Tendani				Sizwe			
	Type-1	Type-2	Type-3	Total	Type-1	Type-2	Type-3	Total	Type-1	Type-2	Type-3	Total
Anticipatory Set	0	2	3	5	0	3	4	7	1	1	4	6
Objectives	0	1	0	1	0	1	0	1	0	1	0	1
Input: Amount/Mol	0	2	8	10	0	2	2	4	0	1	4	5
Input: Counting Unit	0	1	3	4	0	1	1	2	0	3	2	5
Input: Molar Volume	0	0	4	4	0	1	1	2	0	3	0	3
Check Understanding	0	1	5	6	0	4	1	5	0	5	3	8
Guided Practice	0	0	3	3	1	3	0	4	2	1	0	3
Closure	0	0	2	2	2	1	1	4	1	2	1	4
Total per Quality Category	**0**	**7**	**28**		**3**	**16**	**10**		**4**	**17**	**14**	
Percentage (rounded off)	**0**	**20**	**80**		**10**	**55**	**35**		**11**	**49**	**40**	
TOTAL EPISODES	**35**				**29**				**35**			

Lesson Element (Represents a teaching session related to the mole concept in each lesson)	Comparison Group											
	Janet				Christine				Hendrick			
	Type-1	Type-2	Type-3	Total	Type-1	Type-2	Type-3	Total	Type-1	Type-2	Type-3	Total
Anticipatory Set	0	1	1	2	0	0	1	1	1	2	3	6
Objectives	1	0	0	1	0	0	0	0	0	0	1	1
Input: Amount/Mol	0	0	1	1	4	1	1	6	1	1	1	3
Input: Counting Unit	0	2	1	3	1	2	0	3	0	1	3	4
Input: Molar Volume	1	2	0	3	0	1	0	1	1	1	0	2
Check Understanding	2	2	0	4	7	9	1	17	4	2	2	8
Guided Practice	2	6	0	8	0	2	1	3	3	2	1	6
Closure	0	1	0	1	0	0	0	0	0	0	0	0
Total per Quality Category	**6**	**14**	**3**		**12**	**16**	**3**		**10**	**9**	**11**	
Percentage (rounded off)	**26**	**61**	**13**		**39**	**52**	**9**		**33**	**30**	**37**	
TOTAL EPISODES	**23**				**31**				**30**			

As is evident in Table 7.2, the percentage of sophisticated TSPCK episodes for Tendani is only lower than Hendrick, who had 37% compared to Tendani's 35%. However, Tendani's percentage of sophisticated TSPCK episodes is substantially higher than that of Janet and Christine at 13% and 9% respectively. Tendani and Sizwe have higher percentages of

proficient TSPCK episodes than both Janet and Hendrick in the comparison group. Janet has the highest percentage proficient TSPCK episodes at 61%. Christine has the highest percentage of basic TSPCK episodes at 39% and Janet has 26% of basic TSPCK episodes. However, Sipho, in the Learning Study group, had the fewest number of proficient TSPCK episodes, and no basic TSPCK episodes in his lesson. Generally, the teachers in the Learning Study group had a greater percentage of proficient and sophisticated TSPCK episodes, whereas the teachers in comparison group had a greater percentage of basic and proficient TSPCK episodes in their lessons.

The differences in the quality categories of TSPCK episodes between the Learning Study group and comparison group are represented graphically as average percentage per category per group in Figure 7.2 below.

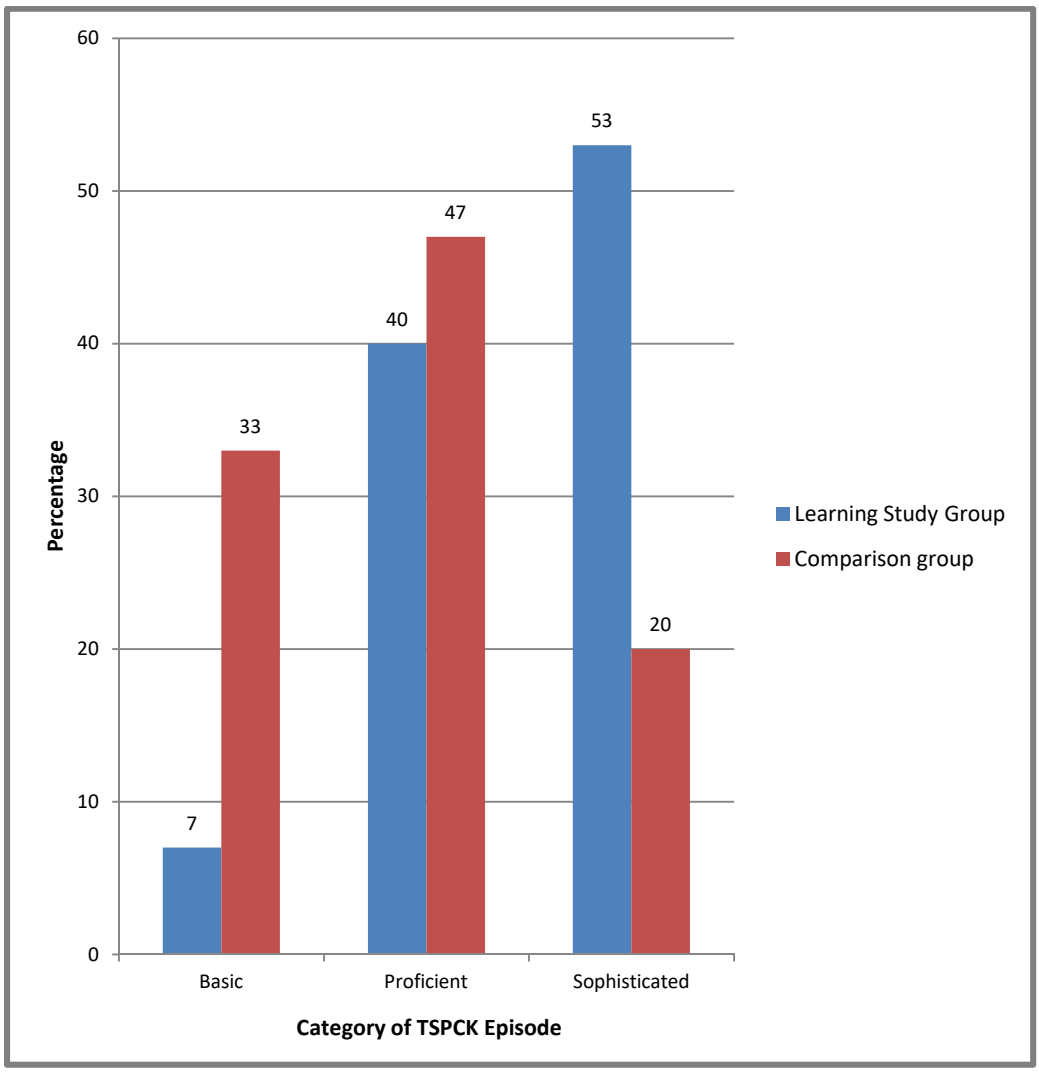


Figure 7.2: Average percentage of TSPCK episodes per quality category for the Learning Study group and the comparison group

In the Learning Study group, only 7% of the TSPCK episodes are basic TSPCK episodes compared to 33% in the comparison group (see Figure 7.2). The Learning Study group also has a higher percentage of proficient TSPCK episodes at 47%, compared to the comparison group at 40%. The biggest difference is that the comparison group has only 20% sophisticated TSPCK episodes compared to 53% in the Learning Study group. These percentages represent more in-depth explanations of concepts by the teachers in the Learning Study group than the comparison group when teaching the mole concept. In the previous section, in terms of the input lesson element, the explanation of the concepts by the teachers in the Learning Study group began with proficient TSPCK episodes and this analysis confirms that.

This subsection has provided a detailed description of the number and percentage of TSPCK episodes in the lessons of the teachers in the Learning Study group as compared to that of the comparison group. Generally, the teachers in the Learning Study group, which worked collaboratively on a lesson in which TSPCK was explicitly used in the planning of the lesson, had slightly more TSPCK episodes than those in the comparison group. The most compelling difference between the two groups is in the percentage of TSPCK episodes per quality category. The Learning Study group had fewer basic episodes and substantially more sophisticated episodes than the comparison group. In the next sub-section, the total number of TSPCK episodes per lesson element is discussed. Each lesson element, with the input element subdivided to include the teaching of the three important relationships encapsulated in the big idea (Furio *et al.*, 2000), represents a teaching session related to teaching an aspect of the mole concept.

Total TSPCK Episodes per Lesson Element

The total number of TSPCK episodes in each lesson element is also shown in Table 7.2. The lesson elements, such as the anticipatory set and objectives, are part of a lesson or activity introduction. Generally, there are fewer TSPCK episodes in these elements. The teachers in the Learning Study group have more episodes in the lesson element, the anticipatory set, than those of the comparison group. There are also, with the exception of Tendani, far more TSPCK episodes in the input lesson element, in which new knowledge is presented through instructional activities (Hunter & Russell, 1976) by the teachers in the Learning Study group than the teachers in the comparison group. With the exception of Hendrick, who had almost

the same number of ‘type 3’ or sophisticated TSPCK episodes in his actual teaching, on the input element as Tendani, generally the teachers in the Learning Study group had far more ‘type 3’, or sophisticated TSPCK episodes than the teachers in the comparison group.

In terms of the lesson element, checking understanding, which is often based on monitoring learning and responding to clues from students (Hunter & Russell, 1976), the number of TSPCK episodes were similar. Christine, however was the exception and had far more TSPCK episodes in this lesson element than any of the other teachers. She was asked far more questions by students, to which she responded. However, in terms of quality, her responses most often were basic or proficient TSPCK episodes. In terms of checking understanding the teachers in the Learning Study group summarised aspects of the lesson with either proficient or sophisticated TSPCK episodes. The number of TSPCK episodes in the comparison group in the guided practice element was greater since the teachers did worked examples with the students, but generally the quality was categorised either as a ‘type 1’ or ‘type 2’ TSPCK episodes. The teachers in the comparison group, with the exception of Janet. had no TSPCK episodes, where two or more TSPCK components were interacting (Park & Chen, 2012) in the closure element whereas the Learning Study group had between two to four TSPCK episodes. This was due to the teachers using samples of equal masses, equal volumes and equal amounts to end the lesson. In the next sub-section, the interconnectedness of TSPCK episodes in the teaching sessions is discussed.

7.4.2. Connections between TSPCK Components from Different Episodes

Miheso and Mavhunga (2018) state that the enacted TSPCK rubric has limitations in that it does not provide an overall grading for a single TSPCK score for enactment, but only reveals the focal character for TSPCK enactment. The rubric allows only the rating of individual TSPCK episodes. For effective TSPCK development, a coherent integration of the components is required, and strong connections between the components is required for teachers to scaffold learning (Park & Chen, 2012). The question therefore arose of how, for example, the different TSPCK episodes in teaching a concept, such as molar volume, were connected to work towards effectively teaching the concept. In addition, from the development of the instrument for measuring the teachers’ TSPCK in stoichiometry and the scoring using the rubric (see Chapter 4), exemplary TSPCK in assessing the item on CTS

required an integration of the other components. For this reason, CTS is considered to subsume the other categories (Mavhunga & Rollnick, 2013). When generating the TSPCK episodes, the category of CTS was only mapped if the teachers used a strategy that focused on aspects of WDT or LPK, and worked towards helping students move towards the correct understanding. Moreover, the recent study, conducted by van der Merwe (2018), revealed that original pre-determined TSPCK episodes in planning were more sophisticated in terms of both their structure and the number of interacting components. In this study, the thorough in-depth analysis also revealed, that a teacher task comprises a number of identifiable TSPCK episodes, especially when using the different lesson elements for effective planning as an analytical tool, since a number of sub-skills, techniques and methods comprise these lesson elements (Hunter & Russell, 1976). This is particularly so for the teachers participating in the Learning Study, as each translated the lesson plan on what was planned as a single TSPCK episode comprised a number of TSPCK episodes in the enacted lesson, especially as the activity was unpacked by the teachers when teaching. This emerging pattern is discussed in detail in the next chapter. A visual means of showing the interconnectedness of the separate TSPCK episodes, that emerged when translated from planning to classroom enactment, could provide a more coherent picture of enacted TSPCK.

Enumerating TSPCK Episode Maps to Generate TSPCK Event Maps

According to Park and Chen (2012), an enumerative approach is useful in portraying the integration of components in a clear and explicit way. A similar approach was therefore used to develop a map, similar to the PCK map used by Park and Chen (2012). Each TSPCK episode map already established the interactions between the components in an episode. This method was used to explore the interconnectedness between the different TSPCK episodes in teaching a concept. Each component in a TSPCK episode had a connection through the interwoven or linear sequence structure. Therefore, each different component in the episode was given a '1', as in the study conducted by Park and Chen (2012). However, a key difference was that, if a component was repeated, it was scored more than once. The episodes related to the teaching of the mole as a counting unit and molar volume were enumerated. For this analysis, the introduction and conclusion of the lessons were not enumerated, as the interconnectedness was only investigated for two of the three activities developed for the Learning Study. Only two were investigated for this study, as these aspects of the mole were the two activities that were not drastically changed through the four cycles

of the Learning Study. Therefore, the three teachers in the Learning Study group all taught these two activities from the basic lesson plan. Episodes from the comparison group that corresponded to teaching the same content were also enumerated. Figure 7.3 illustrates how this was done, using Christine's TSPCK episode maps for teaching molar volume.

In the enumeration table (see Figure 7.3), the possible connections between each TSPCK component were listed. In Episode 19, the TSPCK components CSA, LPK and REP were interwoven. Therefore, each component was scored with a '1' in the enumeration table as shown in Figure 7.3. Episode 20, which was a worked example, had a linear sequence structure. Christine used two different types of symbolic representations and, because the component was repeated, was scored as '2' in the enumeration table (see Figure 7.3). The frequency of the scores between each of the possible ten pairs of TSPCK components, such as LPK-CSA, WDT-REP were then tallied and recorded in the table. These were then added to a diagram in which the five TSPCK components were arranged in a pentagon, similar to the pentagon model used by Park and Chen (2012). CTS was placed at the top since this component subsumes all the other components (Mavhunga & Rollnick, 2013). LPK and WDT were used as the base, since any teaching strategy should begin with either of these components in terms of the CTS component (Rollnick & Mavhunga, 2014).

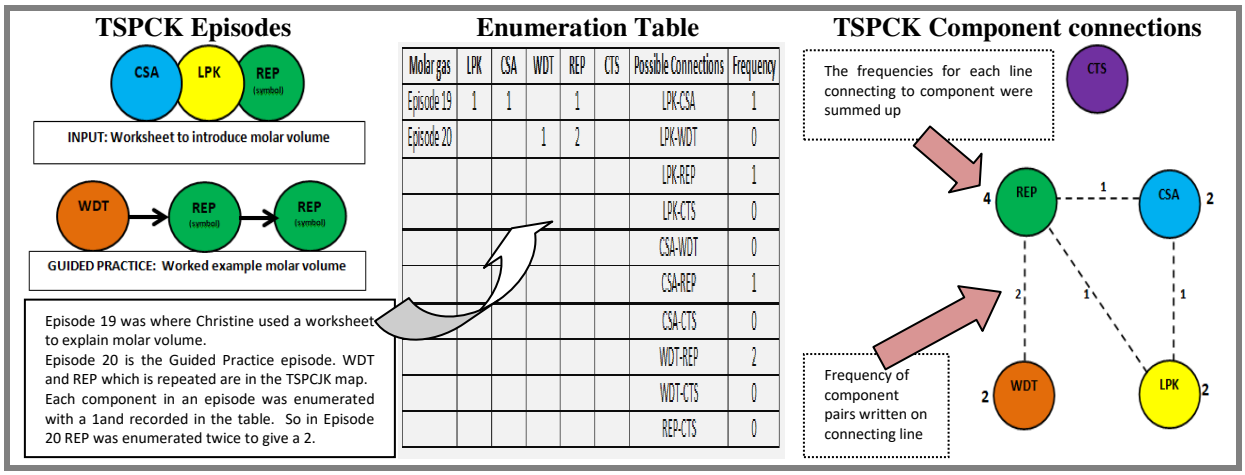


Figure 7.3: Enumerating TSPCK component interactions

The pairs of TSPCK components, with scores in the enumeration table, were then linked using a line as shown in Figure 7.3. The frequency of these connections was then indicated on the line (see Figure 7.3). If the frequency of the TSPCK component pairs was less than five, a stippled line was used to show the connections. For TSPCK component pairs with a frequency above five, a solid line was used. In this case, all the TSPCK component pairs had a frequency of less than five, so all the connections are represented by stippled lines (see

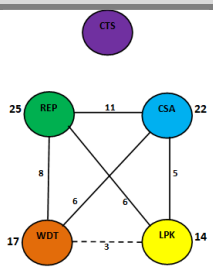
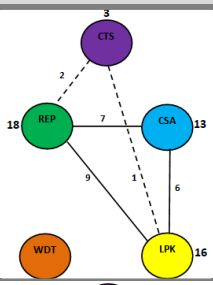
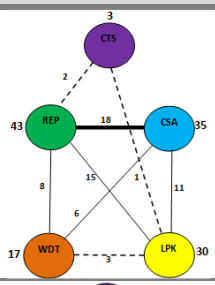
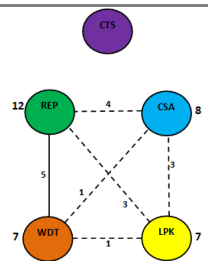
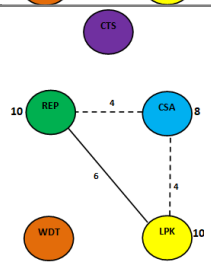
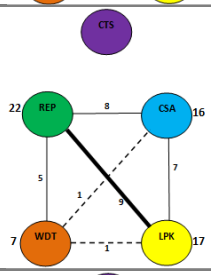
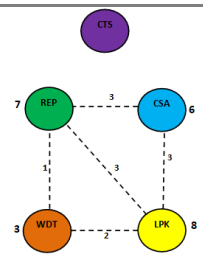
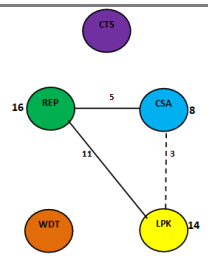
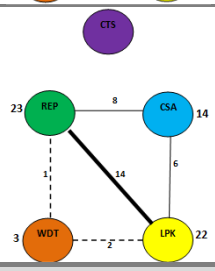
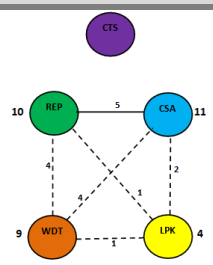
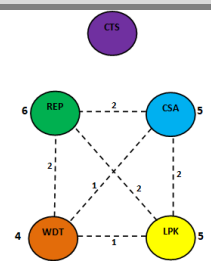
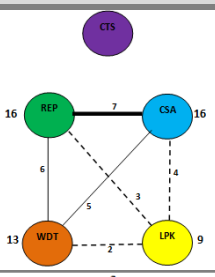
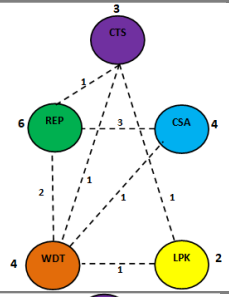
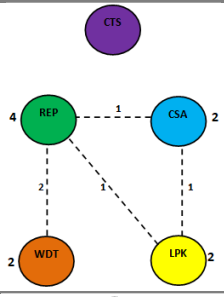
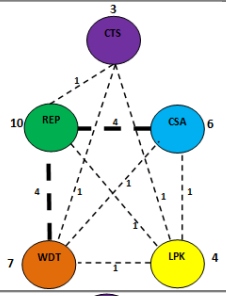
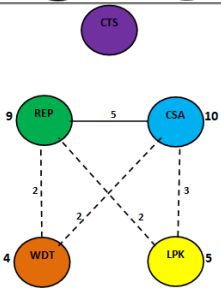
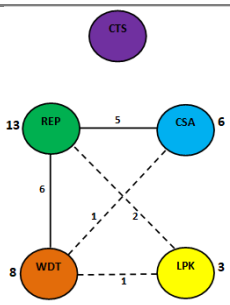
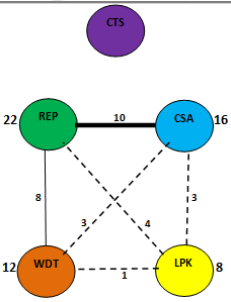
Figure 7.3). The frequencies on all lines that connected to a specific TSPCK component, for example REP, which in Figure 7.3 has connections with WDT, CSA and LPK, were then summed to provide the total number of connections in the two episodes in Christine's lesson that dealt with the concept of molar volume. This was done for all six teachers for two aspects of the big idea, related to the mole, to develop an overall picture of the connections for the TSPCK components between the Learning Study group and the comparison group. The diagram showing the connections between the five TSPCK components to show the interconnectedness, from here on will be referred to as a TSPCK Event map, since it represents the combined TSPCK episodes of a teaching event, teaching activity, or lessons dealing with a big idea in a topic.

The two TSPCK event maps for both groups of teachers were then superimposed on one another to determine the total number of connections between the TSPCK components. The total number of connections between each TSPCK component pair were summed, and checked against the connections in the TSPCK event map for teaching the two concepts against the two individual TSPCK event maps. Table 7.3 summarises the TSPCK Event maps for the teaching of the two concepts analysed for this study and the combined TSPCK Event map. The combined TSPCK event map is in the last column of the table. The component pair with the highest frequency of connections in the combined TSPCK event map is indicated in Table 7.3 with a thick black line. Again, if the frequency was higher than five, the line is solid, whereas if the frequency was lower than five, a stippled line was used.

The Interconnectedness of TSPCK Components in TSPCK Events

The results in Table 7.3 on the next page indicate the interconnectedness of the TSPCK components. The TSPCK event maps shown in Table 7.3 are reproduced in a larger format in Appendix 20.

Table 7.3: TSPCK Event maps for the concepts of the mole as a counting unit and molar volume for teachers in the Learning Study and comparison groups

Topic Teacher	Mole as counting unit	Molar volume	Combined Event maps for both concepts in lessons
Sipho			
Tendani			
Sizwe			
Janet			
Christine			
Hendrick			

The results in Table 7.3 on the previous page indicate that for two-thirds of the teachers, the most common connection is between the TSPCK components CSA-REP. The only two exceptions are for Tendani and Sizwe, where the connection between the component pairs LPK-REP had the highest frequency of connections and those between CSA-REP the second highest. Sipho, who was part of the Learning Study group, had the highest frequency of connections between the component pair CSA-REP, with the connections between LPK-REP the second highest frequency in his TSPCK Event map. Hendrick had the highest frequency between the same component pair (CSA-REP) in the comparison group. The frequency of connections for Hendrick was 10, and this was higher than the frequency of connections for both Sizwe and Tendani in this component pair at 8 connections (see Table 7.3). Christine had the lowest frequency of connections between the component pair of CSA-REP, with a tally of four, which was equal to the connections between the component pair of WDT-REP. For the component pair of LPK-REP, for which Sizwe and Tendani had high frequency tallies, in both cases the tally of the connections between LPK-REP were higher than all three teachers in the comparison group.

In terms of the total number of connections to a TSPCK component from the other components, there are notable differences in some of the components. For example, the connections to LPK in the Learning Study group are higher than that of the comparison group (see last column of Table 7.3). For the component REP, there are also more connections to this TSPCK component in the Learning Study group than there are in the comparison group, with the exception of Hendrick who has the same number of connections to the REP component as Tendani. For the component WDT, the number of connections for teaching molar volume are higher in the comparison group than the Learning Study group. This is due to the fact that the comparison group did worked examples and focused on difficulties related to the mathematical manipulation of the mathematical formula to calculate molar volume. With the exception of Christine in the comparison group and Sipho in the Learning Study group, the number of connections to CSA ranges between a total of ten to fifteen (see Table 7.3). Sipho has the highest number of connections to CSA, at 35, with Christine only having 6 connections. There are also very few connections to CTS in both groups of teachers, despite planning conceptual strategies in the Learning Study.

An interesting observation, related to the pattern of interconnections between the TSPCK components in the Learning Study group, is, despite working off the same lesson plan for

teaching these two concepts, the patterns differ. For teaching the concept of the mole as a counting unit, the pattern of interconnectedness is the same for Sipho and Tendani. However, for Sizwe there is no connection between the WDT-CSA component pair (see column 2 of Table 7.3). The frequency of interconnected component pairs in Sipho's and Tendani's TSPCK Event map is also not equal, with Sipho making more connections between component pairs in every case. The same is evident in the TSPCK Event maps for teaching the concept of molar volume. Although Sizwe and Tendani have the same pattern of interconnectedness, the frequency of interconnections between the component pairs is slightly higher in most cases in Sizwe's TSPCK Event map (see column 3 of Table 7.3). The patterns in the TSPCK event maps for teaching the mole as a counting unit and molar volume for the three teachers in the comparison group have different interconnectedness patterns in each case. This, however, is not surprising, since Park and Chen (2012) found that patterns of interconnectedness between generic PCK components were idiosyncratic and topic-specific. Therefore, when teachers teach a topic, they way they approach teaching the key concepts within a topic would vary based on factors such as experience, beliefs about teaching and the grasp of the concepts within a topic. For example, Janet has a conception of the mole as equal to Avogadro's constant, or an F3 conception (Strömdahl *et al.*, 1994). Therefore, her focus was more on teaching the mole as a number for counting. In addition, Tullberg *et al.* (1994) also conclude that a teacher's conception of the mole influences their teaching approach. So the idiosyncratic nature of the TSPCK event maps for teaching these concepts in stoichiometry can be explained, and it is evident that, within the construct of TSPCK, the approach to teaching concepts within a topic may be concept-specific.

In terms of teaching, for the two aspects related to the big idea of the mole, namely the mole as a counting unit and molar volume, the total percentage of all the connections made by each group of teachers is shown in Figure 7.4. Figure 7.4 summarises the total number of connections between TSPCK component-pairs and the total number of connections between all five TSPCK components from the combined TSPCK event maps for both groups (see Table 7.3).

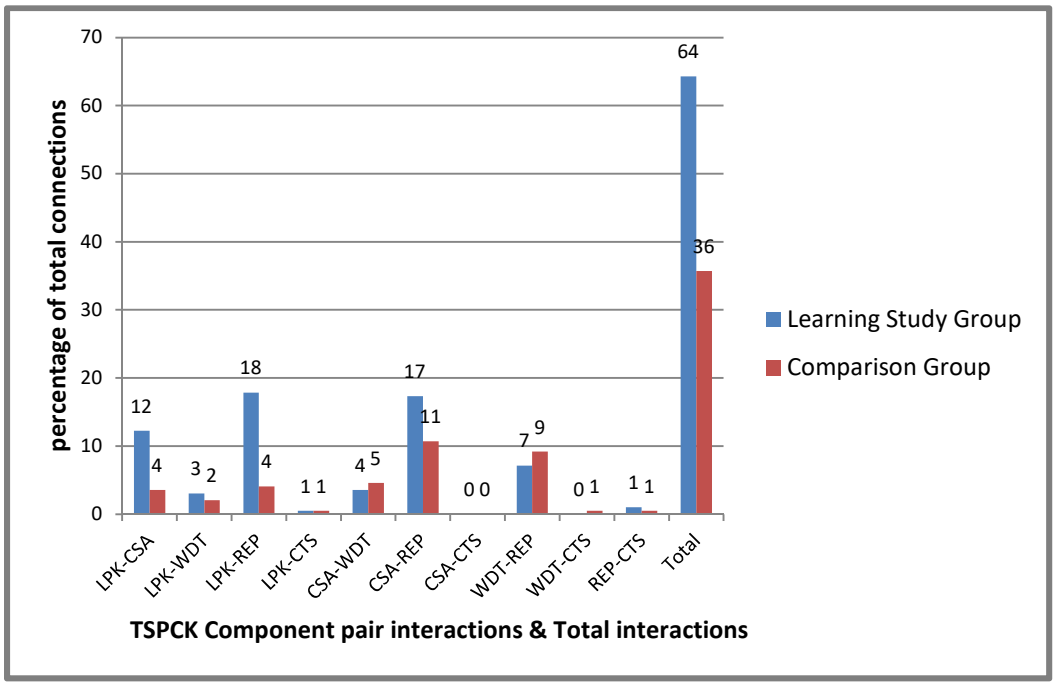


Figure 7.4: Bar graph of percentage of connections between TSPCK component pairs and total connections for the two groups of teachers

As is evident in Figure 7.4, with the exception of the component pairs CSA-WDT and WDT-REP, the percentage of connections between the TSPCK components pairs is higher in the Learning Study group of teachers. From the qualitative analysis of the TSPCK episodes when determining the TSPCK in action profiles, it is evident that higher percentages for the TSPCK component pairs CSA-WDT and WDT-REP in the comparison group is due to the teachers' focus on difficulties students have in doing stoichiometric calculations. The percentage of interactions between component pairs with CTS is very low in both groups. This is disconcerting since the activities in the Learning Study were specifically designed by the team to challenge student difficulties by sequencing ideas and using the three levels of REP. However, the overall percentage of the total number of connections is almost double in the Learning Study group when compared to the comparison group of teachers.

Pattern of Interconnectedness Across the Cycles of the Learning Study

In the Learning Study group, each teacher taught the lesson after a discussion meeting which looked at how the lesson was taught and how it could be improved (see Chapter 7). This begs the question: did each cycle show an improvement in terms of the quality of TSPCK episodes for teaching the different aspects related to the mole? To answer this question, the interconnectedness of the TSPCK components in the TSPCK event maps for the two teaching segments were examined. Sipho taught the second cycle in the Learning Study, followed by

Tendani and then Sizwe. The total number of connections between the TSPCK for each teacher were summed and the results are shown in Figure 7.4. Figure 7.4 plots the percentage of connections for each lesson segment for the three teachers in the Learning Study group in the sequence the lessons were taught.

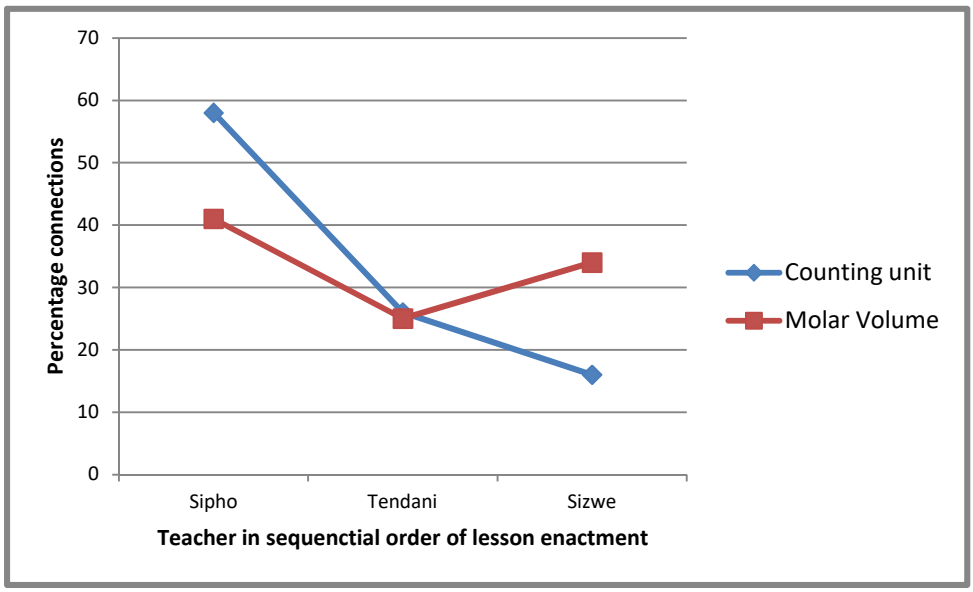


Figure 7.5: Percentage connections between TSPCK components for the three teachers in the Learning Study group

Figure 7.5 shows that there is no increasing pattern of interconnectedness between TSPCK components for the two lesson segments examined based on the sequence of teaching. The patterns of interconnectedness of the TSPCK components do not indicate that there was a successive improvement. For both teaching segments, Sipho, who taught first, had a greater number of connections between the TSPCK components than both Tendani and Sizwe in both teaching segments (see columns 3 and 4 of Table 7.3). Tendani had more connections between TSPCK components in the lesson segment on the mole as a counting unit than Sizwe. Sizwe, on the other hand, had more connections between TSPCK components than Tendani for the teaching event on molar volume. Sizwe, who taught last in the sequence, does not have more connections between the TSPCK components than Sipho and there is no clear increase in either segment when compared to Tendani. Clearly there are other factors that either filter or amplify the translation of the collaboratively planned lesson drawn from the collective TSPCK evident in the PLC, to enacted TSPCK (Gess-Newsome, 2015).

Factors to Account for Patterns of Interconnectedness Across Cycles

The factors identified from the in-depth analysis of the TSPCK episodes provided the evidence to account for the patterns of interconnectedness across the cycles of the Learning Study. A detailed account is provided in Appendix 19, but succinct observations are provided here.

Firstly, the enacted lesson had more sophisticated TSPCK episodes as a result of the discussions in the PLC related to the construct of TSPCK and the collaboratively planned lesson that drew on the collective TSPCK of the team. This is evident in Table 7.3 where there are more connections with the TSPCK component REP with the Learning Study group. The emerging patterns (see Appendix 19) highlight that there are more TSPCK episodes in the enacted lesson than in the planned lesson and that in terms of the use of representations, the sophistication of planned TSPCK episodes, drawn from the group's cPCK is still evident in enacted TSPCK. During the Learning Study, the representations and using the three levels of representation to move away from only using the more complex symbolic level of representation (Gabel, 1999) were a key focus in the planning meetings. After the pilot lesson in which the three mathematical relationships, namely between mass and amount, the number of entities and amount, and the volume of gases at STP and amount (Furio *et al.*, 2000), were introduced at the end of the lesson, subsequent lessons introduced these relationships as part of each activity (see Chapter 5). Therefore, in terms of collective TSPCK of the team evident in the PLC used to plan the lesson, all three levels of representations were part of the structure of the TSPCK episodes planned for in the lesson plan. Sipho in the learning Study group had the most connections with the component REP.

Secondly, when moving from the lesson plan to enacting the lesson, the number of TSPCK episodes increased (van der Merwe, 2018) from that of the lesson plan. This increase in number, which in some cases also resulted in a change in the structure of the episode, was clearly evident from the in-depth analysis of the lessons of the teachers participating in the Learning Study. In some cases this change in structure resulted in enacted TSPCK episodes that were less sophisticated across the cycles. For example, there is evidence from the enacted TSPCK (see Appendix 19), in terms of changing the sequence of aspects of the mole as a counting unit, that teachers used their own personal knowledge, or pPCK when rearranging the sequence of the collaboratively planned lesson. Both Tendani and Sipho had their own

reasoning based on an algorithmic approach to stoichiometry and did not consider the conceptual basis for the sequence of the instructional strategy when making the change. As Gess-Newsome (2015) states: although teachers may rearrange instructional sequences, this is not an indication of a mastery of skills. This therefore had an impact on the pattern of interconnectedness across the cycles.

Thirdly, the first activity in Sipho's and Tendani's lesson was planned as a predict-observe-explain (POE) sequence (Loughran *et al.*, 2012). The teachers working in a PLC were able to draw on the generic knowledge provided by the experts in the PLC in using a specific instructional strategy, understanding student difficulties and organizing the content around the big idea related to the mole (Gess-Newsome, 2015). This is evident in that a lesson was planned that used the components of TSPCK in planning the activity and most of these components are evident in the TSPCK episodes identified in the lesson. During the enacted lesson, there were more TSPCK episodes in practice than the planned TSPCK episode, which was also seen with pre-service teachers in the study conducted by van der Merwe (2018). This resulted in the idiosyncratic patterns of interconnectedness across the cycles of the Learning Study shown in Table 7.3. For example, both Sipho and Tendani have set teaching practices that influenced the translation of the planned TSPCK episode into enacted TSPCK and resulted in a change in the structure and number of TSPCK episodes in enactment. Such teaching practices are often developed through experience and reflection as stored teaching scripts (Stender *et al.*, 2017). Therefore, although there was a collaborative plan when the lesson was enacted, both teachers used their own personal knowledge that resulted in the planned TSPCK episode being modified in classroom enactment. This supports the idea that personal and private understandings are used in the classroom, even when working from a collaboratively developed lesson plan (Gess-Newsome, 2015). In Tendani's case, what was happening in the classroom also influenced the structure and number of TSPCK episodes in his lessons since the moment-to-moment experiences in the classroom also impact on how planned TSPCK is enacted in the classroom (Chan & Yung, 2015). This supports the idea that instruction in the classroom is often adjusted on the rapid clues that happen in the moment (Gess-Newsome, 2015).

Another reason for the patterns of interconnectedness across the cycles can be attributed to the teachers' content knowledge, pedagogical knowledge and beliefs. A key assumption of the TSPCK model is that content knowledge is key for the development of TSPCK

(Mavhunga, 2012). In the TPK&S model, content knowledge is one of the professional knowledge bases from which teachers draw for developing TSPCK (Gess-Newsome, 2015; Rollnick & Mavhunga, 2015). Included in the professional knowledge bases is pedagogical knowledge and knowledge of students. The first example here accounts for Sizwe's pattern of interconnectedness not increasing, despite teaching the last cycle of the Learning Study, due to his kevel of content knowledge. Sizwe, although scoring above the critical acceptable score for CK (see Chapter 4), scored the lowest of the three teachers in the CK instrument. In the in-depth analysis, there were two instances where his lack of understanding of the physical quantity amount and its SI unit - the mole - was evident in his lesson (refer to Appendix 19). Sipho on the other hand, because of his better content knowledge (see Chapter 4) was able to salvage the teaching sequence of the coin analogy when he realised he had made an error when giving students information to do the activity (refer to Appendix 19). The second example, accounts for Tendani's pattern of interconnectedness not increasing despite teaching the lesson after Sipho. All three teachers employed small group work strategy since, in terms of technique, students were guided by teacher questions, handled the equipment, and presented their findings on the chalk board or on the overhead projector (Garrett & Roberts, 1982). One example of where small group work strategy was used was in calculating the amount of substance present in a spatula-full of substance. During the group feedback, Tendani was far less proactive in engaging with students than Sipho and Sizwe and this was evident in the TSPCK episodes in their respective lessons (see Appendix 19). The difference between Sipho's enacted TSPCK and Tendani's enacted TSPCK can be attributed to the knowledge about pedagogy they brought into the classroom. Of the three teachers, Tendani was unable to translate the CTS components into his enacted TSPCK. His lack of knowledge of general PK therefore impacted on him being able to effectively use the CTS component of TSPCK. There is also evidence that, Tendani's belief that 'science teaching involves the transfer of science knowledge through various techniques' (see Appendix 19) may have acted as a filter for him implementing the teaching strategies used in the lessons (Gess-Newsome, 2015).

Finally, when working collaboratively in planning a lesson in a Learning Study, the lesson plan evolves, based on the individual teachers' own experience and intuition (Pang & Marton, 2003). The teacher's own experience and intuition are part of their personal knowledge that is context-specific (Gess-Newsome, 2015). In the participating teachers'

lessons, there were examples of where this personal knowledge was used, and their ideas were incorporated into the lesson that proceeded. The teachers drew on ideas from each other and from the experts in the team when teaching their individual lessons (see Appendix 19). Despite this however, the pattern of interconnectedness across the cycles did not increase (see Figure 7.5) since the teachers' personal knowledge, content knowledge, pedagogical knowledge and beliefs described above impacted on their enacted TSPCK.

This sub-section has looked at the interconnectedness between the TSPCK components in teaching two concepts related to the big idea of the mole. The two concepts analysed were selected specifically because the planning to teach these concepts in the Learning Study, although modified slightly for the mole as a counting unit, remained fairly static through the four cycles of the Learning Study. In analysing the activity on molar volume, the planned sequence included looking at the pictures of the reaction of acids with metals to form hydrogen gas (see Chapter 5). In the two lessons that followed, this was not done, so in doing the analysis for the interconnectedness between components, this TSPCK episode was not included from Sipho's lesson. The TSPCK episodes related to teaching these two concepts, were included in the analysis here from the comparison group. This was done in order to be able to compare the impact of working collaboratively in a Learning Study on the interconnectedness of TSPCK components to determine to what extent this has an impact in practice on enacted TSPCK. The interconnectedness between TSPCK components for each teacher in the Learning Study group were also examined to determine if the last teacher in the sequence displayed better quality TSPCK enactment in lesson segments. However, this was not seen to be the case. The possible factors to account for this were outlined and are described in more detail in Appendix 19.

This section has described a number of the different quality categories of TSPCK episodes, evident from the in-depth analysis of the lessons taught by the teachers who participated in the Learning Study, and the lessons taught by the comparison group. Generally, the quality of the TSPCK episodes ranges between the proficient and sophisticated, whereas, in the comparison group, the quality is generally in the range of basic to proficient. The interconnectedness between components for teaching two concepts related to the big idea - the mole - were mapped on TSPCK event maps. Generally, there were more connections between many of the components in the Learning Study group, as compared to the comparison group. However, can these differences be contributed to the collaborative

participation in the Learning Study? The last sub-section describes the statistical significance of these differences.

7.5. Statistical Analysis of TSPCK Episodes in the Lesson Elements

In the Learning Study, a group of teachers worked collaboratively to plan a lesson that revised the mole concept. The three teachers in the comparison group potentially could collaborate but did not work together in the planning or sharing of resources beyond assessment. These two groups of teachers shared many similar characteristics, such as being experienced Grade 11 Physical Science teachers, with similar initial scores in both the TSPCK Instrument and CK Instrument designed for this study. Furthermore, both groups of teachers taught the same scope of content despite the Learning Study group teaching Grade 11s whereas the comparison group taught Grade 10s. Therefore, the two sets of lessons taught by these two groups shared one important feature: the same big idea and subordinate concepts were taught. Because of the differences in lesson formats, Madeline Hunter's lesson elements for effective lesson planning (Hunter & Russell, 1976) were used as an analytical tool for analysing the lessons to determine comparable lesson segments. This allowed a way to statistically compare the two groups in terms of the enacted lessons and to compare the three teachers in the Learning Study group.

When applying the lesson element format in the in-depth analysis, six of the seven lesson elements were identified in the teaching of the lessons that were used to develop the platforms for the TSPCK episodes. In addition, the input/modelling element was further subdivided into the important relationships and concepts, related to the mole, that was being taught (Furio *et al.*, 2000). As a result of grouping the TSPCK episodes into the various lesson elements as lesson segments when teaching the mole, eight data points were obtained for statistical analysis. These data points were created by finding the average score of the TSPCK episodes in each lesson element for each teacher.

The episodes were scored using the enacted TSPCK rubric developed by Miheso and Mavhunga (2018). Since the enacted TSPCK rubric was used as a scoring tool for observable differences, namely, the number of TSPCK components interacting, the categorisation allowed the TSPCK episodes to be rank-ordered (Lammers & Badia, 2004). Generating these

ordinal scores was therefore not based on subjective categories and could easily be transformed into numerical scores, since the rubric categories were simply used as rating scales, and the rank order was averaged (Wu, 2007). Table 7.4 summarises the average scores obtained for each lesson element. These were obtained by finding the sum of the scores for each teacher in the Learning Study group and the comparison group and dividing the total scores by the number of TSPCK episodes in that lesson element. The raw data is included in Appendix 20.

Table 7.4: Average scores of TSPCK episodes for each lesson element in the Learning Study group and the comparison group

Lesson Element	Learning Study Group				Comparison Group			
	Sipho	Tendani	Sizwe	Average	Janet	Christine	Hendrick	Average
Anticipatory Set	2.60	2.57	2.50	2.56	2.50	3.00	2.33	2.61
Objectives / Purpose	2.00	2.00	2.00	2.00	1.00	0.00	3.00	1.33
Input: Amount/Mol	2.80	2.50	2.80	2.70	3.00	1.50	2.00	2.17
Input: Counting Unit	2.75	2.50	2.40	2.55	2.33	1.67	2.75	2.25
Input: Molar Volume	3.00	2.50	2.00	2.50	1.67	2.00	1.50	1.72
Checking Understanding	2.83	2.20	2.38	2.47	1.50	1.65	1.75	1.63
Guided Practice	3.00	1.75	1.33	2.03	1.75	2.33	1.67	1.92
Closure of lesson	3.00	1.75	2.00	2.25	2.00	0.00	0.00	0.67

The average score for the three teachers for each lesson element in the Learning Study group and the comparison group were subjected to a *Wilcoxon signed ranked test*. The reason the lesson element scores were used, rather than each quality category, was due to the fact that there were only three quality categories. In order to conduct a *Wilcoxon signed rank test,* at least four data sets are required (Stangroom, 2017). However, using the six lesson elements for effective lesson planning (Hunter & Russell, 1976) and further categorising the input lesson element into the three important relationships students need to learn to understand amount (Furio *et al.*, 2000), eight data sets were generated.

For the *Wilcoxon signed rank test,* the null hypothesis was that there was no difference in the average scores for each lesson element between the Learning Study group and the comparison group. Therefore, there should be no significant difference with respect to lesson elements between the lessons of the teachers who worked collaboratively and those who worked independently. A two-tailed test was done, and the mean difference between the average scores for the TSPCK episodes constituting each lesson element between the

Learning Study group and comparison group, was 1.04 with a W value of 1 and a Z value of – 2.38. The Z value can only be used if the sample size is larger than twenty (Stangroom, 2017). Since the sample size was small (N = 8), the results can only be applied to this sample of teachers but the W value is below the critical W value of 3 ($p \leq 0.05$) which indicates that there is a significant difference between the lessons enacted by the two groups of teachers, and the null hypothesis is rejected. Therefore, the lessons based on the overall mean scores in terms of rank order for the TSPCK episodes of the Learning Study group have a significantly statistical difference when compared to the rank order of the TSPCK episodes of the comparison group. Thus for this group of teachers, participation in the Learning Study impacted positively on the lessons they taught, resulting in better mean scores for TSPCK episodes when compared to the lessons of the comparison group.

The average score for each of the three teachers in the Learning Study group were also subjected to *Wilcoxon signed rank tests*. Sipho's average scores per lesson element were compared with Tendani's scores. Then Tendani's scores were compared with Sizwe's scores. The results of this analysis are in Appendix 18. What this analysis showed was that Sipho's lesson, first in the cycle, was significantly better than Tendani's lesson. There was also no significant difference between Sizwe's lesson and Tendani's lesson, although Sizwe taught the lesson in the last cycle after Tendani. However, when Sipho's scores were compared with Sizwe's scores, Sipho's lesson was significantly better than Sizwe's. Therefore, as a group, the three teachers in the Learning Study delivered better lessons when compared to the comparison group but there was no significant improvement in the lessons based on the sequence in which the lessons were taught. Sipho, who taught first in the sequence, did deliver a significantly better lesson than both Tendani and Sizwe. However, Sipho did join the PLC with better quality TSPCK as measured by the TSPCK Instrument (see Chapter 5). There could also be other factors, such as teachers' beliefs, personal knowledge or knowledge of the generic teacher knowledge bases that could act as either filters or amplifiers, or impact on how the collective TSPCK evident in the PLC is translated in enacted TSPCK by each teacher when the teachers in the Learning Study group taught the lessons (Gess-Newsome, 2015).

This section has looked at the number and quality of the TSPCK episodes between the teachers participating collaboratively in a Learning Study with three teachers working independently in the same school. Generally the number and quality of the TSPCK episodes

were better in the Learning Study lessons when compared to the comparison group, as seen in the TSPCK in action profiles and the analysis of the TSPCK quality categories. The teachers in the Learning Study group have far fewer basic TSPCK episodes and far more sophisticated TSPCK episodes, in terms of percentage of TSPCK episodes per quality category. The teachers in the Learning Study group have more proficient and sophisticated TSPCK episodes, whereas the comparison group have far more basic and proficient TSPCK episodes. This difference speaks to the quality of the teachers' explanations when teaching stoichiometry. The interactions between TSPCK components for both groups were mapped on TSPCK event maps to show the interconnectedness between components, and generally the Learning Study group showed greater interconnectedness between most of the components. The teachers in the Learning Study group also had a higher percentage of interconnected TSPCK components than the comparison group, highlighting better integration of TSPCK components when teaching specific concepts. When the TSPCK episode mean scores were compared in terms of the lesson elements of an effective lesson, the difference between the Learning Study group and the comparison group for the lessons of these two groups was found to be statistically significant. Since the equivalence between the two groups was established at in Chapter 3, with the only difference being the participation in the Learning Study, this statistically significant difference in the two groups' lessons can be attributed to the one group's participation in the Learning Study.

7.6. Summary

This chapter has analysed the data related to the teachers' enacted TSPCK when teaching the mole concept. In order to determine to what extent participation in a Learning Study had on the enacted TSPCK of the participating teachers, their enactment of the lesson was compared to that of a comparison group of teachers. The teachers in the Learning Study group, based on the TSPCK in action profiles, indicated that the teachers in the Learning Study group's explanation of concepts was generally better than those of the comparison group. The Learning Study group of teachers' TSPCK episodes were mostly clustered around either proficient or sophisticated TSPCK episode categories, whereas the comparison group had more basic or proficient TSPCK episodes. To develop a better understanding of these differences of the TSPCK episodes between the two groups of teachers, a more quantitative approach to the number and quality of the TSPCK episodes was also conducted, using the lesson elements for an effective lesson (Hunter & Russell, 1976). The lesson elements were

used as lesson segments, representing time units for teaching the different aspects of the mole concept to make a fairer comparison, due to the highly varied lessons observed. The teachers in the Learning Study group, based on this analysis, had a greater number of TSPCK episodes in the different lesson elements, and had a smaller percentage of basic TSPCK episodes when compared to the comparison group. Their quality of the TSPCK episodes also ranged from proficient to sophisticated whereas the comparison group ranged more from basic to proficient. When the individual TSPCK episodes were mapped using a similar procedure used by Park and Chen (2012) to generate TSPCK Event maps, the Learning Study group had more connections between components than the comparison group. However, there was no increase in the interconnectedness between TSPCK components across the cycles of the Learning Study based on the sequence in which each teacher taught the lesson. When the mean scores of the TSPCK episodes in the lesson elements were compared, the lessons for the Learning Study group were found to be significantly better than those of the comparison group. This chapter has established that the teachers' enacted TSPCK is better in terms of the quality, interconnectedness and mean scores of the quality categories. In the final chapter the findings from this study will be discussed and, where appropriate, conclusions and recommendations made.

CHAPTER EIGHT

Discussion and Implications

This chapter provides a brief summary of what the study was about. The findings are discussed in relationship to the research question that guided this study. The implications of the findings are discussed in relation to the contribution this study makes to the TSPCK research community in particular, in finding ways to determine the quality of teachers' TSPCK through the interconnectedness of TSPCK components, and the PCK community in general. Based on the findings, recommendations and suggestions for further studies are made. Lastly, the limitations of the study and personal reflections of the process are discussed.

8.1. Introduction

The purpose of this study was to explore the potential of experienced teachers working collaboratively in a Learning Study in the development of teachers' topic-specific PCK and to determine the extent that the collective TSPCK evident in a Professional Learning Community impacted on classroom enactment. The topic of focus in this study was stoichiometry, which deals with the quantitative aspects of chemical reactions (Kolb, 1978; Silberberg, 2006). In order to explore the potential of a Learning Study as a professional learning activity, it was first necessary to determine the quality of experienced Physical Science teachers' topic-specific pedagogical content knowledge (TSPCK) and content knowledge (CK) in the topic of stoichiometry. This required the design and validation of an instrument that could be used to determine the quality of the TSPCK of teachers in the topic of stoichiometry, and determine any changes in TSPCK after participation in a Learning Study. Since content knowledge is deemed a necessary precursor for the development of PCK (Kind, 2009a), an accompanying valid CK instrument needed to be developed.

The topic of stoichiometry is notoriously difficult for students to learn, and teachers struggle to teach it effectively (Gulacar, Overton, Bowmanc*, et al.*, 2013). This has been confirmed in the South African context by students' performance in stoichiometric calculations in the final matriculation examinations. According to the diagnostic reports, these questions are poorly answered, since the majority of learners are unable to solve stoichiometric problems (Department of Basic Education, 2011b, 2013, 2014). These observations are consistent with

the literature, which highlights the difficulties encountered by learners in solving stoichiometric problems (Schmidt, 1997; Tóth & Sebestyén, 2009). This has also led to calls for stoichiometry to be taught more thoroughly in Grade 10 and 11, and to form part of teacher development (Department of Basic Education, 2013, 2014).

The first phase of this study therefore aimed at determining the quality of pedagogical content knowledge (PCK) in the topic of stoichiometry in order to identify areas for teacher support and development (Kind, 2009b). The second phase of this study aimed at determining how a Learning Study, as a collaborative professional learning activity, impacted on the development of teachers' PCK in stoichiometry, or TSPCK and influenced classroom enactment.

This study therefore served a twofold purpose. Firstly, it attempts to establish the quality of a sample of experienced teachers' TSPCK in stoichiometry, to identify areas for teacher support and development, to improve their teaching practice. Secondly, it tries to determine the change in teachers' TSPCK, and the impact on enacted TSPCK, in the classroom through participation in a Learning Study. This study aims not only to contribute to the growing literature on instruments to determine the quality of TSPCK in specific science topics, but also the complexity of TSPCK component interactions in classroom enactment. A brief summary of the study is provided in the section that follows before discussing the findings of this study.

8.2. Overview of the Study

This study was framed within teacher knowledge and classroom enactment. Due to both the tacit nature of teacher knowledge that influences classroom enactment, and the complex nature of teaching, a mixed methods approach was employed. This allowed both a breadth and depth of TSPCK development and enactment through participation in a Learning Study to be to be explored that would not have been possibly through either a purely qualitative or purely quantitative approach. The triangulation therefore provided a more accurate picture of the impact of the Learning Study. A complex multiphase design that built on other basic mixed methods designs was employed (Creswell, 2012). During the first phase of the study, a sequential exploratory design was used to measure the quality of experienced Physical Sciences teachers' TSPCK. During Phase I, qualitative data and then quantitative data was collected from instruments designed for my M.Sc research project (Malcolm, 2015). The

results of the data from Phase I of the study was analysed both quantitatively and qualitatively to determine the quality of TSPCK in stoichiometry. The data collection and data analysis are summarised diagrammatically in Figure 8.1.

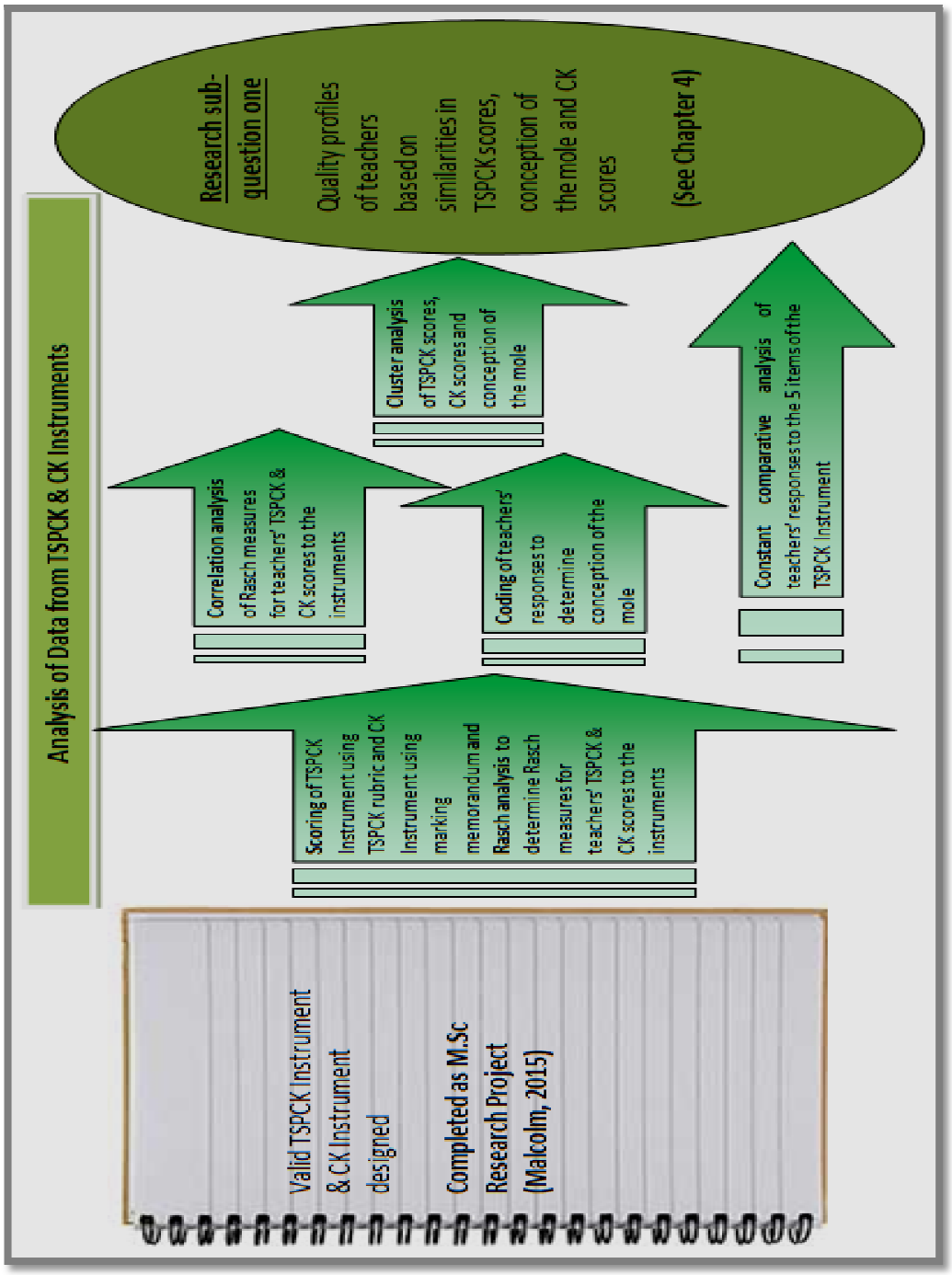


Figure 8.1: Summary of Phase I of Study

The data analysed in Phase I was then used to plan an intervention for a professional learning activity. This involved constituting a Professional Learning Community which participated in a Learning Study during the second phase of the research (see Figure 8.2).

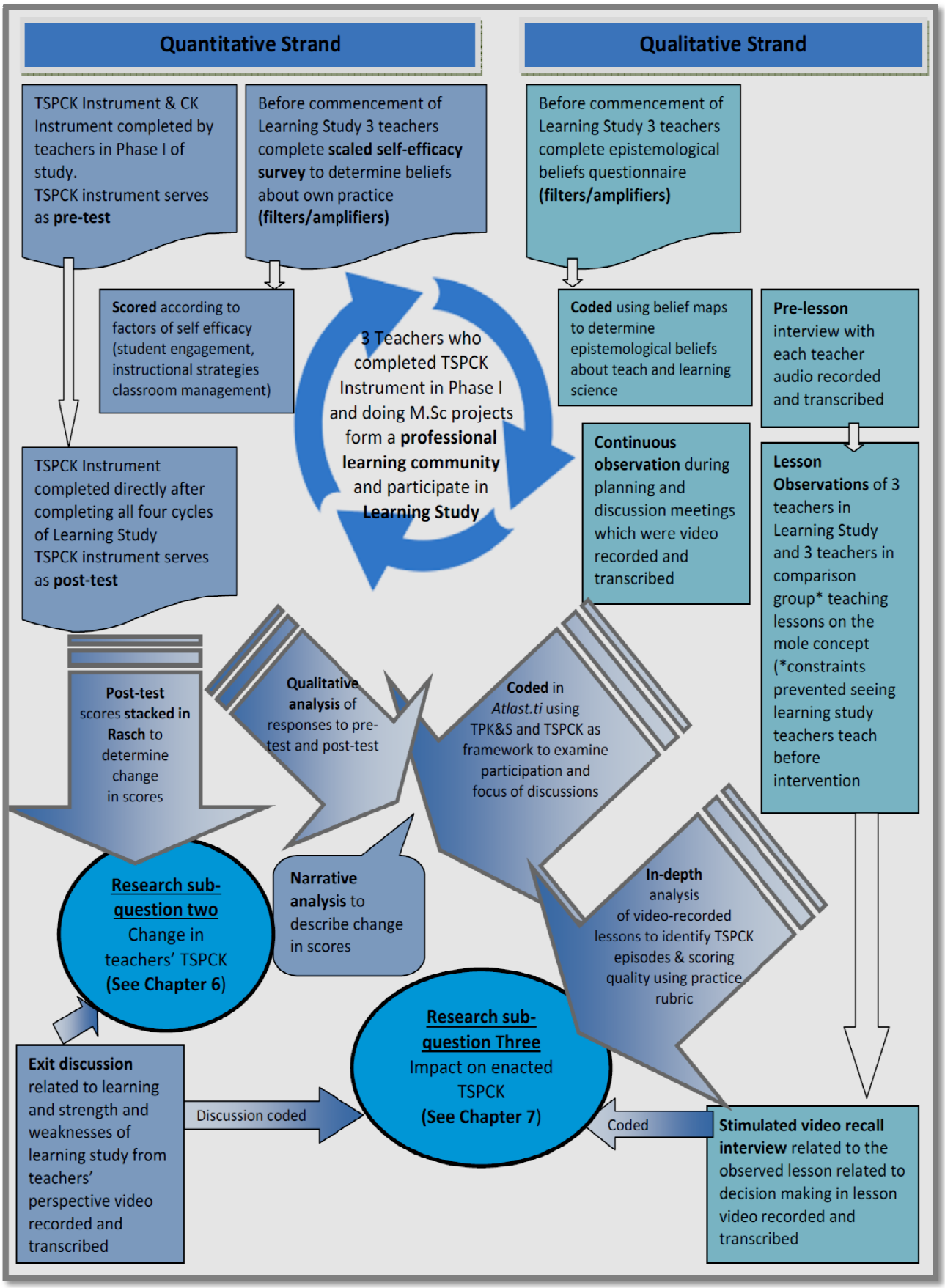


Figure 8.2: Summary of Phase II of the Study

During Phase II, a convergent parallel design was used in which quantitative data and qualitative data were collected separately and then merged (Creswell, 2012). The data collection and data analysis are summarised diagrammatically in Figure 8.2. Phase II of the study aimed to investigate, firstly the impact of a Learning Study on the development of teachers' TSPCK. Secondly, it tried to investigate how and to what extent interactions in the collective PCK evident in a Professional Learning Community engaged in the planning and discussion of a lesson impacted on the enacted TSPCK of the teachers in the classroom.

This section has provided a brief diagrammatical overview of this study in which a multiphase mixed methods research strategy was employed. In a mixed methods approach data was collected, analysed and interpreted from both qualitative and quantitative approaches (Tashakkori & Creswell, 2007). A mixed methods approach allowed the research questions of this study to be addressed since the quality of teachers' TSPCK, the development of teachers' TSPCK in a collaborative Learning Study and the impact on enacted TSPCK required both a narrative and numerical approach (McMillan & Schumacher, 2010). The mixed methods approach was carried through to the analysis of the data, allowing for new perspectives to be added to understanding TSPCK, the construct under investigation, and drawing attention to the complexities and anomalies for the topic of stoichiometry (Foss & Ellefsen, 2002). In the section that follows, a discussion reflecting the findings answering the research question for this study is provided.

8.3. Discussion of Findings

This study was guided by the following research question: 'To what extent is experienced science teachers' measured and enacted TSPCK developed during a Learning Study designed with the explicit inclusion of TSPCK for the topic of stoichiometry?' In order to answer this question, three important sub-questions were asked. These were:

1. What is the baseline quality of experienced physical sciences teachers' topic-specific PCK and content knowledge in stoichiometry of teachers teaching in the province of Gauteng?
2. How and to what extent is the topic-specific PCK of experienced teachers developed through participation in a Learning Study?

3. How and to what extent is the collective topic-specific PCK evident in a Professional Learning Community enacted in the teaching practices of the teachers teaching the mole concept?

Each of the above sub-questions is layered and each layer investigated contributed to answering these questions and are discussed below.

8.3.1. Quality of Experienced Teachers' Topic-specific PCK and Content Knowledge in Stoichiometry

In order to explore the impact of a Learning Study on the development of teachers' TSPCK and enactment in the classroom, the quality of teachers' TSPCK was an unknown variable that needed to be measured. Since there was no existing instrument to measure teachers' TSPCK in stoichiometry, an instrument had to be developed to do so (Malcolm, 2015). Since PCK development is linked to a teacher's content knowledge (Kind, 2009a), there was also a need to develop a CK Instrument in order to determine the relationship between teachers' TSPCK and CK. This subsection briefly discusses the results in terms of the quality of TSPCK and CK and teachers' conception of the mole.

The Quality of Respondents' TSPCK in Stoichiometry

The distribution of raw scores to the five categories of the TSPCK instrument provided an overall qualitative indication of the teachers' TSPCK in stoichiometry (Rollnick & Mavhunga, 2014). The majority of teachers' scores centred around developing TSPCK and for the other components centred around basic levels of TSPCK, although a large proportion of the teachers centred around developing TSPCK for the item on representations (see Chapter 4). The item on learner prior knowledge was, however, the exception centring around developing and, as has been mentioned, many teachers are aware of student misconceptions and can identify them (Gomez-Zwiep, 2008). Teachers struggled to indentify big ideas in stoichiometry, which has been described as difficult for teachers (I. Mitchell *et al.*, 2017).

However, in order to understand the quality of PCK, it is important to understand the interaction of the components (Abell, 2008). Since the validation of the TSPCK instrument demonstrated that the instrument measured a single construct (see Chapter 4), the in-depth qualitative analysis yielded an interesting link between the Rasch scores and the integration

of components. The examples provided in Section 4.3.3 highlighted that those teachers with higher logit scores made specific links in their responses to the other items, whereas those with low logit scores tended to show no links between the components in their responses. The logit scores therefore not only provide a measurement of the overall quality of the respondent's TSPCK but hint at the extent to which the responses show an interaction of components.

As mentioned above, the logit scores hint at the level of integration of the TSPCK components. However, it is admitted that this may only be valid for this sample of teachers. The constant comparison analysis of the teachers' responses of the component, conceptual teaching strategies, also provided insight into two important aspects related to the quality of the teachers' TSPCK in stoichiometry. Firstly, evidence is provided of the integration of components. Secondly, it provided insight into the teaching approaches to stoichiometry (see Chapter 4). The teaching strategies described in most cases provided an algorithmic approach for solving the problem without challenging the students' errors directly. Teachers often have an awareness of student misconceptions, as was evident in the high raw scores for the item on learner prior knowledge, but the responses to the item on conceptual teaching strategies indicated that teachers are often unable to address these misconceptions (Gomez-Zwiep, 2008). The strategies described by most of the teachers did not challenge the misconceptions in order to bring about conceptual change (Hewson, 1981; Strike & Posner, 1982).

All of the teachers sampled proposed symbolic representations in their teaching strategy since stoichiometry does deal with the quantitative aspects of chemical change (Kolb, 1978). The teaching strategies described by the sampled teachers therefore mirror the different methods identified by researchers in how students solve stoichiometric problems. Most teachers sampled did not use macroscopic analogies, and none of the teachers included actual demonstrations or practical work, for students to qualitatively see evidence of reacting ratios which, according to Tsaparlis (2009), is essential for developing conceptual understanding. During the observations of the comparison group of teachers in Phase II of the study, two of the teachers did use practical work when teaching molar concentration where students made up standard solutions. This highlights the limitations of only measuring TSPCK in a topic using one approach, as the responses may have been very different if the Category E item dealt with a misconception related to molar concentration (Morrison & Luttenegger, 2015). This possibly also hints to the idea, that just as PCK was seen to be topic-specific (Park &

Chen, 2012), this specificity may even be concept-specific, thus extending the taxonomies of PCK introduced by Veal and MaKinster (1999). This is discussed when answering the research question related to enacted TSPCK. None of the teachers sampled use all three levels of representation to explain limiting reagents, which, as Gabel (1999) states, is due to teachers not integrating the three levels of representation into their own thinking. It is conjectured that this could be due to the difficulties students have with making the necessary connections between macroscopic representations and submicroscopic representations, due to its abstract nature (van Berkel *et al.*, 2009).

The Conception of the Mole Held by the Respondents Surveyed

The respondents' conception of the mole was determined by a question in the CK instrument. The categories of conceptions, classified by Strömdahl *et al.* (1994), were used to code responses to this question. Less than half of the respondents had a conception of the mole that was consistent with the SI definition of the mole and defined it as the unit for amount of substance, although the curriculum documents place emphasis on this definition. A number of researchers have highlighted the importance of the conceptualisation of the mole as the SI unit for amount of substance for effective teaching of stoichiometry (Staver & Lumpe, 1993; Strömdahl *et al.*, 1994). If more than half of the science teachers hold a conception of the mole that is not consistent with the SI definition, it is possible that this contributes to the poor performance of learners when answering stoichiometric questions. On the other hand, if the mole is treated as number or counting unit, learners can solve stoichiometric problems correctly (DeToma, 1994; Strömdahl, 1996). However, the ability to solve stoichiometric problems correctly does not necessarily indicate conceptual understanding (Gauchon & Méheut, 2007). The influence of teachers' conception of the mole on learner performance was beyond the scope of this study but when investigating the relationship between teachers' TSPCK and CK, groupings of the teachers sampled became evident on their reported approaches to teaching stoichiometry. This was confirmed through cluster analysis and these results are discussed below.

The Relationship between the Respondents' Measured TSPCK in Stoichiometry and their Stoichiometric Content Knowledge

The respondents' level of CK was determined through the CK instrument (see Appendix 11 for a discussion on the validity and reliability of the CK Instrument). Secondly, the

relationship between the measured TSPCK and CK was determined by means of correlation analysis and significance testing. The majority of teachers therefore demonstrated good content knowledge in stoichiometry. The Rasch analysis of the items helped to identify problematic areas of CK evident in some of the responses to the items. These are general observations, however, and do not detract from the overall good demonstration of CK among the respondents (see Appendix 14). Items in which less than half the respondents answered correctly were conceptual in nature. This analysis raised some interesting possibilities. Firstly, studies have found that learners can be taught to solve stoichiometric problems algorithmically but are unable to solve problems that assess conceptual understanding (BouJaoude & Barakat, 2003; Tóth & Sebestyén, 2009). Secondly, learners fail to grasp chemical concepts if they fail to link chemical changes at a macroscopic level to a mental model of the entities involved at a submicroscopic level (Bond-Robinson, 2005). Thirdly, the term 'amount' has a very specific meaning in stoichiometry but many teachers do not use this term and, as a result, learners are unable to solve stoichiometric problems (Packer, 1988). Could teachers possibly have the same difficulties or do learners struggle because teachers do not focus on these aspects when teaching stoichiometry? Without supporting evidence through interviews, however, this is purely conjecture at this juncture.

The correlation analysis was conducted using Pearson's product-moment correlation. The correlation coefficient indicated that there is only a moderate positive relationship between the measured TSPCK and CK of the respondents, which has been found in many studies (e.g. Mavhunga, 2012; Ndlovu, 2014). This relationship was statistically significant. The moderate correlation coefficient, however, implies that this relationship has some predictive value regarding the relationship between the measured TSPCK and CK (Creswell, 2012). Therefore, the following observations are noteworthy. In this sample, no teachers demonstrated a mean ordinal score, indicating limited TSPCK, since the majority scored well in the category *learner prior knowledge* (LPK). This finding was similar to those reported on by Mavhunga (2012) for chemical equilibrium, Ndlovu (2014) for electrochemistry and Vokwana (2013) for organic chemistry. Just over half of the teachers with high levels of CK exhibited developing TSPCK or basic TSPCK, an indication that possessing CK does not necessarily translate into developing PCK (Gess-Newsome, 1999b). An interesting phenomenon was observed in that two respondents scored high TSPCK with low CK that could indicate a transfer of their pedagogical transformation competence (Mavhunga, 2016)

due to their familiarity with TSPCK. The final aspect, in terms of describing the quality of teachers' TSPCK, is to link their conceptions to the mole and their TSPCK and CK scores, which is done below in the last part of this sub-section.

Impact of Respondents' Conceptions of the Mole on the way they Propose to Teach Stoichiometry and the Quality of their TSPCK

Based on the correlation analysis, similar groupings of teachers were evident in terms of their levels of TSPCK and CK, and these were determined using cluster analysis (Mooi & Sarstedt, 2011; Tryfos, 1998). The cluster analysis was used to identify teacher profiles, which were then described from the in-depth analysis, in terms of the quality of TSPCK, CK and their conception of the mole and hence teaching strategies. From the cluster analysis and the constant comparative analysis, there is some indication that teachers' conception of the mole influences their teaching strategies (Tullberg *et al.*, 1994). However, unlike the teachers in Sweden in the study conducted by Strömdahl *et al.* (1994), teachers who conceptualise the mole as a number taught more conceptually than those who conceptualise the mole in a manner that is consistent with the SI definition. Teachers who conceptualise the mole as a number of particles possibly link the ideas of single particles and their relative atomic/molecular/formula mass with Avogadro's number of particles and the mass of Avogadro's number of particles (Fang *et al.*, 2014). What was evident was that teachers who conceptualise the mole as either a number or a mass unit in the algorithmically adequate group use a procedural approach due to the conceptual difficulties related to their conception of the mole, and hence rely on teaching an algorithmic approach for rote learning (Fang *et al.*, 2015; Tullberg *et al.*, 1994).

This sub-section has described the findings of the quality of teachers' TSPCK and CK in stoichiometry. The quality was measured using specifically designed instruments for this study. Not only was this important in establishing the unknown variable of TSPCK, but a valid TSPCK instrument was created which could be used to measure change in TSPCK after a professional learning activity. In terms of the quality of teachers' TSPCK, a number of findings indicate that, generally, the teachers sampled teach stoichiometry algorithmically. There is also evidence that teachers' conception of the mole influences their teaching strategies as suggested by Tullberg *et al.* (1994).

8.3.2. The Extent of Teachers' TSPCK Development through Participation in a Learning Study

The second research sub-question was related to measuring the impact of a Learning Study on the development of teachers' TSPCK through participation in a Professional Learning Community. The construct of TSPCK served as the grammar of practice for both the planning and discussions of the lesson conducted (Grossman, 2011). The Learning Study was the goal-directed action (Jaworski, 2008) which served as the platform to reflect, discuss and inform classroom enactment (Baird *et al.*, 1991; Brodie, 2011). The underlying idea was to see how the explicit inclusion of TSPCK in the planning and discussion of the lesson impacted on teachers' TSPCK development. This sub-section will therefore discuss, firstly to what extent participation in the Professional Learning Community impacted on the teachers' TSPCK. Secondly, this subsection will discuss how participation in the PLC impacted on the teachers' TSPCK development.

The Extent of Teachers' TSPCK Development in Stoichiometry

The development of a valid and reliable instrument to measure TSPCK in stoichiometry still provided the means to answer this research sub-question. The three teachers completed the instrument in Phase I, which served as their pre-test scores and in Phase II they completed the instrument as a post-test at the conclusion of the Professional Learning Community (PLC) activities. As discussed in Chapter 6, this study required the use of an unconventional, yet statistically sound procedure that was used to determine teachers' change in scores where the data was stacked. From the second Rasch analysis with the stacked data, all three teachers improved their scores and their placement on the Rasch measure improved considerably. All three teachers' post-test scores placed them between the respondent with the highest Rasch measure and the group of the next highest five performing teachers. This is evident in the person-item map shown from the two sets of Rasch analyses shown in Figure 8.3 below.

First Rasch analysis

```
MEASURE                                  Person - MAP - Item
                                             <more>|<rare>
     19                                  2V05  +
     18                                        +
     17                                        +
     16                                        +
     15                                        +
     14                                        +
     13                                        +T
     12                                       T+
     11                                        +
     10                                        +
      9                                        +
      8                                        +
      7                                        +S
      6                                       S+  CSA
      5          1V03  1V16  2P04  2P05  2V17  +  CTS
      4    1L01  1V01  2P02  2P03  2P07  2V12  +  WDT
      3                                        +
      2                           1V02  1V08   +
      1                                        +
      0                                        +M
     -1          1P01  1P06  2P08  2V09  2V11 M+
     -2                                        +
     -3                                        +  REP
     -4                                        +
     -5                                        +
     -6 1L02 1V13 2C01  2C02  2V04  2V07  2V10  +
     -7                                       S+S
     -8                     1C03  1L03  2V14   +
     -9                                        +
    -10                           1V06  2V15   +
    -11                                       +
```

Second Rasch analysis (stacked)

```
MEASURE                                  Person - MAP - Item
                                             <more>|<rare>
     19                                  2V05  +
     18                                        +
     17                                        +
     16                                        +
     15                            1L04  1L06  +
     14                                       T+
     13                                       +T
     12                                        +
     11                                        +
     10                                        +
      9                                        +
      8                                  1L05  +
      7                                       S+
      6                                       +S
      5          1V03  1V16  2P04  2P05  2V17  +  CSA    CTS
      4                                        +
      3    1L01  1V01  2P02  2P03  2P07  2V12  +  WDT
      2                           1V02  1V08   +
      1                                        +
      0                                       M+M
     -1          1P01  1P06  2P08  2V09  2V11  +
     -2                                        +
     -3                                        +  REP
     -4                                        +
     -5                                        +
     -6 1L02 1V13 2C01  2C02  2V04  2V07  2V10  +
     -7                                       S+S
     -8                     1C03  1L03  2V14   +
     -9                                        +
    -10                           1V06  2V15   +
    -11                                       +
```

Figure 8.3: Person-item maps to show development in TSPCK based on performance in TSPCK Instrument

The second Rasch analysis was able to show the learning gains as in other studies that have used Rasch in stacking data (Herrmann-Abell *et al.*, 2013; Pentecost & Barbera, 2013), albeit by assuming the post-test scores represented different people in a larger sample. Since the only difference in the pre-test and post-test was when they were administered, before and after the Learning Study, these differences can be attributed to the intervention (Herrmann-Abell *et al.*, 2013). How the Learning Study contributed to these changes is discussed in the next part of this sub-section.

The Development of Teachers' TSPCK in Stoichiometry

In the second Rasch analysis that included the post-test scores, misfiting values were closely analysed, as unexpected responses based on person ability provided insights into some of the changes in scores (Bond & Fox, 2001; Boone & Rogan, 2005). A qualitative analysis of the pre-test and post-test responses revealed the reasons for the change in scores. These were presented in a narrative analysis for Sipho's, Tendani's and Sizwe's learning in Chapter 6. The narrative analysis revealed that all three teachers had instructive beliefs regarding their role as teachers (Luft & Roehrig, 2007), with Sipho and Sizwe moving towards more learner-centred approaches, particularly in the *conceptual teaching strategies* (CTS) item after the Learning Study. Tendani, on the other hand, due to his self efficacy and

epistemological beliefs, and that he was 'teaching to exams', showed no improvement in the CTS item. His beliefs amplified aspects of his learning (Gess-Newsome, 2015) related to *what is difficult to teach* (WDT), which is why he was flagged as misfiting in the Rasch analysis. The narrative also revealed what each teacher felt they gained through the Learning Study, but the implementation of this learning in practice, beyond this project would be either modified or rejected based on contextual factors (Gess-Newsome, 2015).

The teacher's learning was linked to the interactions in the PLC by describing the grammar of practice, in this case the specialised knowledge for examining practice (Grossman, 2011; Stoll & Seashore Louis, 2007). The planning and discussion meetings were coded as described in Chapter 6 into talk units at three levels. Although aspects of the logistics of the Learning Study were discussed in the meetings, much of the talked related to the specialised knowledge which increased across the different cycles of the Learning Study. In the same vein, as the PLC developed the shared repertoire of the tools to discuss the lessons in terms of TSPCK, the debate, which dominated the first meeting, decreased over the cycles of the Learning Study (Wenger, 2011).

An analysis of the TPK&S talk units did reveal that at some point in the five meetings, each aspect of the TPK&S model was discussed. Contextual factors were discussed in the first meeting as the PLC planned the lesson. Knowledge of learners was discussed particularly in the last discussion meeting. This was due to the lack of student gains other than in the algorithmic question in the diagnostic testing of learners that was used to inform discussions in the meetings. Although the activities were planned as conceptual teaching strategies focusing on student difficulties, the PLC failed to consider aspects of student cognition, an important component of knowledge of students (Gess-Newsome, 2015). As a Learning Study, the activities were designed around aspects of variation of the object of learning and what students needed to discern about the mole concept (Ling, 2012); however, the PLC failed to capitalise on the aspects of variation for student learning. The TPK&S talk units also indicated there was considerable discussion related to pedagogical knowledge, but this focused on group work and student participation rather than on aspects related to conceptual change. The PLC fell into the trap of being activity driven, focusing on the activities rather than students conceptual development and student learning (Kind, 2016). This, however, in the context of this study is understandable since the focus was on teachers' TSPCK development and not student outcomes. This does, however, reinforce the notion of teaching

as problematic as described by Loughran (2010). He states that there are many competing demands in teaching making it dilemma-based, challenges that have to be managed and professional learning is embedded in the journey. This is discussed in more detail in the implications section of this chapter.

Chapter 6 also focused specifically on TSPCK talk units. It was this engagement and explicit discussion of student errors and misconceptions that was the cause of the improvement in scores for learner prior knowledge for all three teachers and what is difficult to teach for two (Brodie, 2014). The TSPCK component of representations was also extensively discussed as part of the Learning Study and the number of proficient and sophisticated TSPCK episodes in the enacted TSPCK indicates the development of the teachers' TSPCK in this component (Nilsson, 2014). In terms of curricular saliency, it was also noted that the Learning Study did not have a substantial impact on the teachers' selection of big ideas in stoichiometry as only the big idea related to the mole was the object of learning. They did all, however, select the mole as a big idea and this supports the idea that selecting big ideas is challenging (Loughran *et al.*, 2012; I. Mitchell *et al.*, 2017).

In terms of the teachers' participation, the expert members had substantially more talk units than the participating teachers. The teachers were under the perception that their participation increased as *'we began to feel more comfortable and contribute more*'. Sipho made this comment and related it to the building of relationships that allow members of a community to learn from each other (Wenger, 2009). The extent to which experts participate in such PLC is one of the tensions typical in a PLC where teacher practitioners work with teacher education experts (Jaworski, 2008). However, it is also one of the benefits since they provide expert input related to the content and teaching (Briscoe & Peters, 1997; LaFee, 2003). The expert members were an essential part of the PLC, in helping the teachers to remain focused on the construct of TSPCK, in analyzing the lessons, ensuring that the three levels of representation were integrated into each planned activity and did not reinforce misconceptions in other topics. Their role, therefore, also helped ensure the smooth working of the team and that the PLC remained on task (Jaworski, 2008). However, despite this inherent tension what is clearly evident is that the interactions in the community between the experts and the teachers resulted in learning (Wenger, 2009). The findings of this study highlight the potential of collaboratively developed PCK and add credence to the findings of studies that teachers

develop a deeper understanding of content and refine their PCK through collaborative professional learning activities (Daehler & Shinohara, 2001; Falk, 2012; N. S. Wilson, 2008).

A key finding of this study is that the gains in the quality of TSPCK can be attributed to the explicit inclusion of TSPCK in the planning and discussion meetings of the PLC. These findings are consistent with those made by Mavhunga (2012) that the explicit inclusion of TSPCK in an intervention develops TSPCK and Nilsson (2014) that participation in a Learning Study develops the PCK of the teachers involved. One of the most significant comments made by Sipho was that he felt they did not critically engage each other in terms of their practice, and, without the guidance of the experts, the teachers may have typically focused on easily observed superficial aspects of the lesson (Lewis, Perry, Hurd, & O Connell, 2006). There is evidence that, in this case, the interactions in the PLC, in terms of the collective TSPCK evident in the PLC, contributed to the teachers' learning, and the guidance from the experts kept the teachers focused on aspects of TSPCK that contributed to the gains in the quality of the teachers' TSPCK. A key factor to consider is that the teachers participated in the Learning Study as part of a research project for a post-graduate degree. Toerien (2017) found that post-graduate studies played a significant role in the development of teachers' TSPCK. In the next sub-section, the impact of practice is discussed.

8.3.3. The Impact on Teachers' Enacted TSPCK in the Classroom Through Participation in a Learning Study

The third research sub-question was related to investigating how and to what extent the collective TSPCK evident in PLC was enacted in the classroom. In the previous sub-section, the teachers' TSPCK development through the explicit inclusion of TSPCK in the planning and critical engagement of the lesson was discussed. In answering this sub-question, TSPCK component interaction in TSPCK episodes are discussed. The interaction of TSPCK components was first described by Mavhunga (2015) in the written planning, or collective TSPCK of pre-service teachers in the topic of chemical equilibrium. The translation of collective TSPCK from lesson plans into enacted TSPCK in the classroom has recently been elucidated by investigating pre-service teachers' lessons in stoichiometry during teaching experience (van der Merwe, 2018). This sub-section discusses how and to what extent the interactions, in terms of the collective TSPCK evident in the PLC impacted on enacted TSPCK, in teaching the lesson on the mole concept. In answering this research sub-question,

this knowledge was expanded on and a method of providing an overall picture of TSPCK in a topic was developed.

The Extent to which the Collective TSPCK Evident in the Professional Learning Community Impacts on Enacted TSPCK

In order to determine to what extent the collective TSPCK evident in a PLC impacted on enacted TSPCK, the teachers' lessons were compared to a comparison group of teachers who had also completed the TSPCK instrument in Phase I of this study. The equivalence between the two groups of teachers was established in Chapter 3. Due to the differences in the type of lessons taught, and their length, there was a need to determine a set method for describing the context, or platforms from which the natural interaction of TSPCK components emerged (Mavhunga, 2015). The lesson elements for effective lesson planning (Hunter & Russell, 1976) were used for this purpose, as they not only provided research-based (Wolfe, 1987) contexts from which the TSPCK component interactions could be compared, but also provided the necessary teaching segments for comparison. The use of these generic pedagogical contexts, related to lesson planning, therefore provided the pedagogical platforms from which to display the emergence of the interaction of TSPCK components (Mavhunga, 2015).

The extent of the interactions of the TSPCK components between the Learning Study group and comparison group was described in detail in Chapter 7. The TSPCK episodes from both groups of teachers were described pictorially in TSPCK episode maps, and were categorised based on the number of interacting components, using a classroom enactment rubric developed by Miheso and Mavhunga (2018). By using the lesson elements as platforms when mapping the TSPCK episodes, provided a means to statistically compare the lessons of the two groups of teachers. Another key finding of this study is that the lessons of the Learning Study group were found to be significantly better in terms of the number of the quality categories of TSPCK episodes than those of the comparison group. This provides evidence that Learning Study provided the teachers with a means to develop their engagement in teaching in terms of the components of TSPCK in the enacted lessons (Nilsson, 2014). Nilsson (2014) argues that teachers' participation in a Learning Study is helpful in getting teachers to reconsider aspects of their science teaching which could account for this observation. However, the statistical analysis also showed that there was no significant

difference between the lessons in terms of the number of quality categories of TSPCK episodes of the teachers in the Learning Study group based on the sequence in which they taught the lessons. This suggests that there are other factors that impact on the teachers' engagement in teaching, even when a lesson is collaboratively planned in a Learning Study. The TSPCK episodes revealed that teachers' baseline content knowledge and pedagogical training contributed to this, and that beliefs acted as filters in enactment.

The interconnectedness of TSPCK components in teaching concepts were displayed in TSPCK event maps. From these maps, which were displayed in Table 7.3, it was seen that the teachers in the Learning Study group had substantially more connections between TSPCK components than the teachers in the comparison group. What was evident from the TSPCK event maps was that the patterns of connectedness differed for each teacher. Even in the Learning Study group, working off the same lesson plan, patterns, although similar, in some cases differed. The idiosyncratic patterns therefore suggest the TSPCK is concept-specific. Since the teaching of a topic is based on teaching the important concepts or big ideas that make up that topic (Loughran *et al.*, 2012), it therefore makes sense that this is the case and accounts for the observation made by Park and Chen (2012) that PCK is topic-specific. The TSPCK event maps also provided a visual representation that illustrated the TSPCK component-pairs with the most interconnectedness. The Learning Study group generally had the most connections between the TSPCK component pairs. Interestingly, the Learning Study group had a similar number of connections between WDT-REP but the Learning Study group focused on aspects related to practical work, whereas the comparison group focused on difficulties with calculations. This difference alludes to contextual factors influencing enacted TSPCK, which is discussed in the next part of this sub-section. The TSPCK event maps, therefore, can provide a meaningful overall picture of teachers' TSPCK in a topic. This is discussed in more detail in the next section of this chapter. The next part of this sub-section describes the emerging patterns from the TSPCK episodes.

Therefore, a third significant finding of this study is that the collective TSPCK evident in the PLC impacted on the enacted TSPCK of the teachers. Evidence has been provided to indicate how collective TSPCK was translated into enacted TSPCK, firstly through a greater sophistication of enacted TSPCK episodes, particularly with the use of different levels of representation. Secondly, there was an increase in the number of TSPCK episodes when moving from planned TSPCK to enacted TSPCK (Mavhunga & van der Merwe, 2017). There

is also empirical evidence that confirms the theoretical model of TPK&S and this is discussed in the implications section of this chapter.

8.4. Contribution to Understanding of Teacher Knowledge

In the previous section, the findings of this study were outlined. In this study, the lesson elements described by Hunter and Russell (1976) were used to develop the platforms from which the interaction of components emerged. This was key to comparing the lessons of the teachers. TSPCK event maps were also used to provide an overall picture of the TSPCK of teachers for teaching concepts. Finally, the emerging patterns of the TSPCK episodes provided empirical evidence for the TPK&S model. These aspects are the contributions that this study makes, to current ideas about teacher knowledge and TSPCK. Firstly, this study contributes to the methodology of reporting on the interaction of TSPCK components when constructing TSPCK episode maps. Secondly, this study suggests a method to report on the interactions of TSPCK components in a holistic TSPCK event map that can map all the TSPCK episodes for a lesson, or a series of lessons in a topic. Lastly, this study provides some empirical evidence that contributes to the understanding of the current model of teacher knowledge, the Teacher Professional Knowledge and Skill, or TPK&S model.

8.4.1. Contribution to the Understanding of Enacted TSPCK

Due to the interwoven nature of the interaction of TSPCK components, it is acknowledged that teacher knowledge for teaching is complex (Mavhunga, 2015). The shift from TSPCK in evident in lesson plans to enacted TSPCK is also complex, as it is influenced by both pedagogical reasoning in planning and interactions with learners when teaching (Mavhunga & van der Merwe, 2017). This was shown in this study when describing the emerging patterns evident, when moving from a collaboratively developed lesson plan to enacting the lesson taught in the Learning Study. Furthermore, when looking at the extent to which participation in a Learning Study impacted on enacted TSPCK, there was a need to find a way to compare lesson segments from platforms that were grounded in aspects related to effective lesson planning. The use of an enacted TSPCK rubric to quantify the quality of enacted TSPCK episodes was also limited, as it did not provide a way to gain an overall indication of enacted TSPCK. This sub-section therefore provides recommendations that offer solutions to these two issues and contribute new knowledge to the field of TSPCK.

The Platforms from Which TSPCK Component Interactions Emerge

The mapping of TSPCK episodes, in which the interaction of two or more TSPCK components emerged was first described by (Mavhunga, 2015). These are considered as critical for not only portraying TSPCK but for developing TSPCK. In the study conducted by van der Merwe (2018), pre-service teachers' self-generated TSPCK episode maps were examined and there was no indication as to how the platforms were determined or decided on. However, moving beyond the scope of studies thus far that have investigated TSPCK measurement using specifically designed instruments or the development in preservice teachers' TSPCK with practicing teachers posed some challenges. These included finding a way for comparing the TSPCK of teachers teaching very different lessons.

It is generally agreed that PCK is embedded in enactment in the classroom (Van Driel, Verloop, & de Vos, 1998). Padilla *et al.* (2008) attempted to take this into account by analysing PCK development by employing the Conceptual Profile Model in order to understand how university professors' conceptual profile based on their beliefs, experiences and cultural backgrounds influenced practice. Although it is acknowledge that beliefs filter and amplify how topic-specific collective PCK is translated into enacted PCK, since teachers struggle to articulate their knowledge about what they do as practitioners, examining enactment from effective lesson planning seemed more expedient. Therefore this study focused on manifestations of PCK in classroom enactment (Rollnick *et al.*, 2008). It was for this reason therefore, that when analysing enactment, that instructional practices that are identifiable in the classroom were used rather than trying to access teacher thinking and the way that teachers structured their knowledge.

For this study, the set of instructional practices for effective lesson planning, referred to as lesson elements were used as the platforms for TSPCK episodes (Hunter & Russell, 1976). Effective lesson planning works hand-in-hand with pedagogical reasoning and particularly transformation as described by Shulman (1987). There is a link between aspects of pedagogical reasoning and effective lesson planning, and these links can be used to develop a common practice when mapping out TSPCK episodes. These links are outlined diagrammatically. The links between pedagogical reasoning explained in detail in Bishop and Denley (2007) are linked to the lesson elements as shown in Figure 8.4. For example, Bishop and Denley (2007) highlight that critical interpretation is the first stage of transformation in

which teachers interpret content, engage with it critically and decide how to present it to learners. This is linked to the lesson element objectives in which the teacher selects a learning objective at the appropriate level of difficulty and complexity for their students and make these known to the students (Hunter & Russell, 1976). The other links are shown in Figure 8.4 below. Therefore, the use of lesson elements in the TSPCK episode platforms provides a way that allows TSPCK episodes to be compared and contributes to the methodology of reporting on enacted TSPCK for future studies.

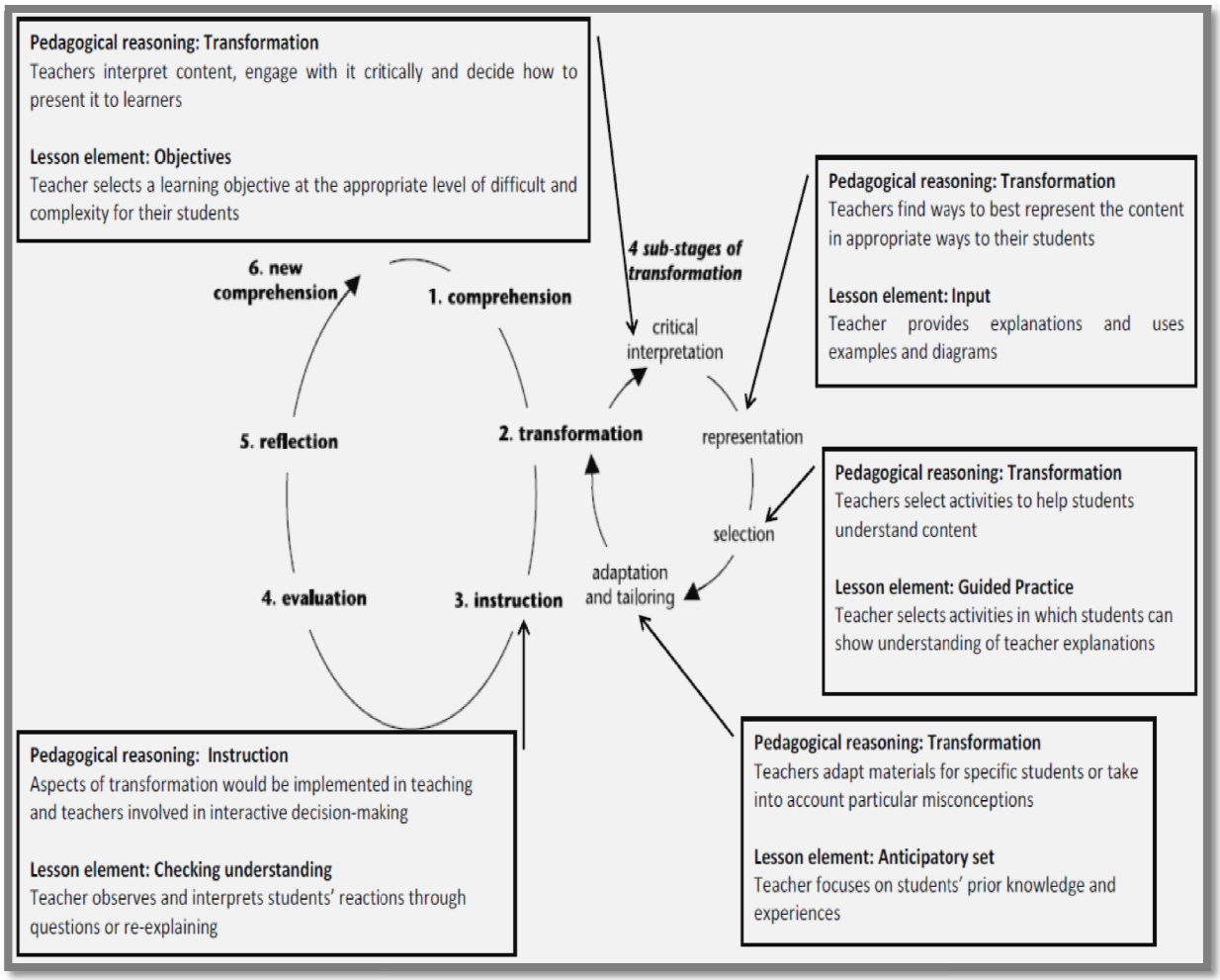


Figure 8.4: Pedagogical transformation processes (Bishop & Denley, 2007)with links to lesson elements

The above has shown how the lesson elements are linked to pedagogical reasoning. It is therefore argued, that in moving forward within the TSPCK research community, it is essential that in mapping out TSPCK episodes, there is a shared language (Wenger, 1998a). The links between the lesson elements and aspects of pedagogical reasoning were outlined above in Figure 8.4. The advantage of using the lesson elements is that they have been shown through the process-product research paradigm to be influential in learning (Wolfe, 1987),

and therefore link aspects of TSPCK and pedagogy in lesson planning for effective teaching. In Chapter 3, a detailed description of the lesson elements were provided, including the sub-set of skills for teaching and learning activities that can contribute to the shared repertoire of the TSPCK community in describing the platforms from which TSPCK component interaction emerges. The added benefit is that an examination of the platforms can provide insight into the array of models of teaching and learning used by teachers (Hopkins & Stern, 1996).

TSPCK Event Maps to Provide Picture of Overall Quality of TSPCK

The TSPCK episode maps and their categorisation in terms of quality based on the number of interacting components using the enacted TSPCK rubric was limited in that this did not provide an overall single picture of the quality of the teachers' TSPCK (Miheso & Mavhunga, 2018). According to Park and Chen (2012), the integration and interconnectedness of PCK components is essential for the development of PCK. Using their method of enumerating interactions based on the TSPCK episodes of the teachers, a map was developed to show the interconnectedness of the TSPCK components. This map was similar to a generic pentagon map created by Park and Chen (2012), but was adapted for TSPCK. In this study, the term TSPCK event map was coined to describe the interconnectedness of TSPCK components from the entire cluster of TSPCK episode maps for teachers teaching a particular concept related to a big idea (see Chapter 7). TSPCK event maps can also be superimposed to provide a picture of the interconnectedness of concepts in teaching a big idea, and these can be superimposed to provide an overall picture of the quality of teachers' TSPCK in a topic. The TSPCK Event maps therefore contribute to the field of reporting on teachers' TSPCK by providing a new tool to report on the overall picture of teachers' enacted TSPCK when teaching a lesson or for a topic. Below is a description of how the TSPCK event map provides an overall picture of teachers' TSPCK.

Figure 8.5 below represents an idealised TSPCK event map for a topic to illustrate how it can be used to provide an overall picture of the quality of TSPCK in a topic. The component of CTS is placed at the apex of the map since this component subsumes all the other components (Mavhunga & Rollnick, 2013). According to Rollnick and Mavhunga (2014), all conceptual teaching strategies should begin with either of the components WDT or LPK, hence these two components form the base of TSPCK event map. Ideally, there should also

be a link between the components LPK and WDT, since the descriptor in the TSPCK rubric for developing and exemplary TSPCK indicates that teachers need to identify specific concepts for the item WDT and provide reasons linked to specific learner prior knowledge and/or misconceptions.

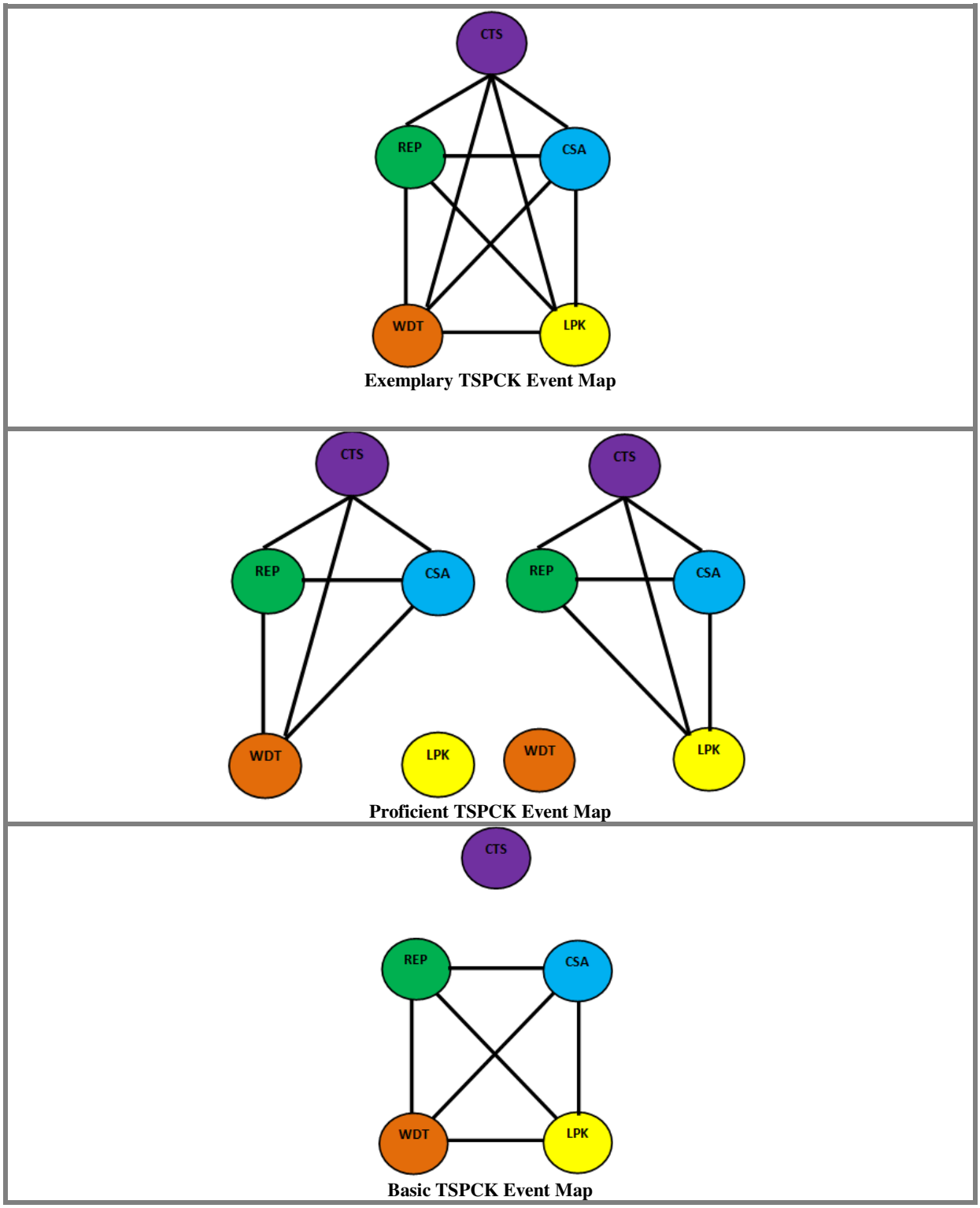


Figure 8.5: An idealised TSPCK Event Map with connections between all five TSPCK components and possible permutations to represent the quality of TSPCK

All the components should also be linked to CTS, since exemplary TSPCK for this component requires teachers to explicitly confront learner prior knowledge or misconceptions, consider at least two aspects of curricular saliency and use different levels of representations in their teaching strategy (see Appendix 2 for rubric). Therefore, exemplary TSPCK in theory should have connections between all five components (see Figure 8.5). Since all conceptual teaching strategies should either begin with WDT or LPK a teacher who doesn't link LPK and WDT might have TSPCK event maps that only show links between four components as shown in Figure 8.5 and this could represent proficient TSPCK. Teachers who do not use conceptual teaching strategies would have no links to CTS and this could represent basic TSPCK (see Figure 8.5). This however needs to be investigated in further studies.

Various studies (e.g. Akın & Uzuntiryaki-Kondakci, 2018; Aydin & Boz, 2013; Aydin *et al.*, 2015) have used PCK mapping based on the work first done by Park and Chen (2012). In all of these studies the idiosyncratic nature of PCK due to its topic specificity has been highlighted. The use of the topic-specific PCK model to map interconnectedness, as was done in this study rather than the generic PCK components, provides a better understanding of the topic-specific nature of PCK. With the revision of the consensus model the grain size of PCK, first described by Veal and MaKinster (1999), at a discipline level and a topic level are acknowledge (Carlson & Daehler, in press). Therefore the studies that have mapped the generic components of PCK have been able to map the connectedness between components when teachers use inquiry-based learning (Park & Chen, 2012) or argumentation (Suh & Park, 2017) and link science teaching orientations to the patterns of interconnectedness between these generic PCK components (Aydin *et al.*, 2015). Therefore these studies provide a picture of PCK at a discipline level rather than at a topic level. This is problematic since the consensus definition for PCK specifically focuses on the knowledge and skills for teaching a particular topic (Gess-Newsome, 2015).

Another potential strength of mapping TSPCK in TSPCK event maps as was employed in this study was the approach that was used. Firstly, the TSPCK episodes were mapped and this allowed the components to be used more than once in a TSPCK episode map where the teachers used different levels of sophistication for the components. During the enumeration this allowed components to be scored based on the number of times they appeared in the TSPCK episode maps that helped overcome the weakness of not taking into account the

strength of the connections between PCK components (Park & Chen, 2012). Aydin and Boz (2013) attempted to overcome this by using a rubric that allocated scores to the interactions based on the level of integration. Although this study did allow for a better enumeration of components, the mapping can be improved by allocating scores to each connection based the TSPCK enactment rubric (Miheso & Mavhunga, 2018) in order to distinguish between the quality of the interactions as was done by Aydin and Boz (2013). This would provide a better picture of teachers' TSPCK not only in terms of the number of interconnections but the quality of the connections.

8.4.2. Contribution to the Understanding the TPK&S Model

The TPK&S model, described in Chapter 2 formed part of the theoretical framework for this study. This model, referred to as the consensus model, is currently being refined (Berry *et al.*, 2017). For this study, the Topic Specific Professional Knowledge was replaced with the TSPCK model, as the two constructs have been described as being aligned (Rollnick & Mavhunga, 2015). However, in this study, particularly teachers' conception of the mole and the role this plays in the way teachers' teach stoichiometry (Strömdahl *et al.*, 1994; Tullberg *et al.*, 1994) has been a thorn in my side as a researcher throughout this study. This is discussed in this section in terms of topic-specific professional knowledge. The findings of this study also have implications that contribute to the understanding of this model and the interactions between the knowledge bases which are also discussed.

Is there Topic-Specific Knowledge for Teaching in Stoichiometry?

In this study, the construct of TSPCK, as outlined in the theoretical framework in Chapter 2, replaced topic-specific professional knowledge in the TPK&S model since these two constructs are considered to be aligned (Rollnick & Mavhunga, 2015). In Chapter 2, some of the problems associated with the mole as a unit were also outlined and the various conceptions that teachers and their students have about the mole that are inconsistent with the SI definition were described (Strömdahl *et al.*, 1994). Tullberg *et al.* (1994) also outlined that a teacher's conception of the mole impacts on their teaching strategies. Tullberg *et al.* (1994) also provided a teaching model for teaching stoichiometry that was linked to the TSPCK component of curricular saliency in the theoretical framework. However, this teaching model, although entwined with this component, influences the teaching strategies the teachers use for teaching stoichiometry. Since the teachers who completed the instruments in Phase I were not

interviewed about their conceptions of the mole, it was not possible to explore these aspects. However, this study has certain aspects which can be speculated on.

Firstly, Furio *et al.* (2000) state that understanding a scientific concept involves more than just knowing its scientific definition but that it is also important to know what changes it has undergone. This therefore is not just knowledge drawn from a teacher's content knowledge. However, generally teachers are unfamiliar with the content related to how the theoretical and practical understanding of chemistry, or chemistry content develops (Olsson, Balgopal, & Levinger, 2015). The definition of the mole has evolved over time and this had led to difficulties in teaching the mole concept (Dierks, 1981). Zaragoza and Fernández-Novell (2008) suggest that understanding the historical background of certain chemistry concepts could help students understand these concepts better. Such knowledge is neither part of a teachers' generic content knowledge per se nor part of a teachers' TSPCK. However, such knowledge may just be necessary to help students understand the definition of the SI quantity amount of substance and its unit the mole better.

Secondly, in the teaching model proposed by Tullberg *et al.* (1994), they refer to the strategic plan for teaching the mole, which they state are the key concepts that are the necessary prerequisites for understanding the mole. This is part of the TSPCK component curricular saliency. However, Fang *et al.* (2014) argue that to understand the mole concept it is important that the definition of amount of substance be linked explicitly to two of the important prerequisite concepts. The SI definition of the mole has two aspects. There is the mass aspect in terms of 12 grams of carbon. Then there is the number aspect that relates the number of particles found in 12 grams of carbon. Both of these aspects, the mass and the number of particles are linked to the SI definition of the mole (Fang *et al.*, 2014). There are therefore two prerequisite concepts at a particulate level that need to be linked to the mole concept. The first prerequisite concept at the particle level, that of the atomic model, in other words, single particles such as atoms, or molecules, or formula units need to be linked to the mole concept with Avogadro's number (Fang *et al.*, 2014). The second prerequisite concept at the particle level is that of relative atomic/molecular/formula mass which needs to be linked to the mole concept through the molar mass. These linking concepts according to Fang *et al.* (2014) need to be taught before introducing the physical quantity amount of substance and its SI unit the mole. This knowledge again goes beyond just aspects of curricular saliency as a component of TSPCK and generic content knowledge. To meaningfully teach the mole

concept, teachers need to guide students in understanding the links between the particulate concepts and the mole concept.

Thirdly, in the teaching model proposed by Tullberg *et al.* (1994), they also propose a tacit plan for introducing the mole, or motivating learning about the mole. In the theoretical framework, this was again linked to curricular saliency and the application of stoichiometry and conceptual scaffolding for other topics. However, a science knowledge base includes more than specific content and needs to include knowledge of the scientific enterprise and the role of science in society (Evans *et al.*, 2006). According to Evans *et al.* (2006), there is a disconnect between the work of chemists and the way chemistry is taught in schools. Chemists explain phenomena, analyse matter and synthesise new substances and have a collection of procedures and models, or a toolbox that support these three activities. As such stoichiometry is not just a topic in chemistry but is part of that toolbox. Teachers tend to approach the teaching of chemistry in a rigid and unidimensional way. However, teachers need to find ways to reason and engage in chemistry in more authentic contexts (Talanquer, 2013a, 2013b). Therefore, teachers require knowledge of how to find ways to link how chemists work in authentic contexts. Teachers need to think beyond the unidimensional rigid idea of stoichiometry as just a topic and its importance in other topics but find ways to show students its relevance as part of a chemist's toolbox, beyond just topics like chemical equilibrium, the gas laws and acids and bases where stoichiometric calculations are done. Teachers should consider ways of using stoichiometry in topics such as rates of chemical reactions, redox reactions, electrochemistry and organic chemistry and thereby enrich and diversify the content they teach (Talanquer, 2013a).

Lastly, there is the issue related to the use of amount of substance. In the pilot lesson, a concerted effort was made to specifically use the amount of substance. Tendani was able to refer to amount of substance where as the other two teachers continued to refer to the number of moles (see Chapters 8). For Sizwe, this had an impact on his enacted TSPCK (see Appendix 19). According to Packer (1988), teachers that use the term 'number of moles' or refer to the symbol n as the mole are not providing their students with the necessary scientific language to successfully solve stoichiometric problems. The word amount is used in both non-formal every-day language and scientific language (Strömdahl, 2008). Learning is about making meaning and language is the basic tool which students do to use this (Pekdağ & Azizoğlu, 2013). Strömdahl (2008) emphasises the need for teachers to be able to discern the

critical features of polysemy words such as amount. These include discerning its every-day meaning, its scientific quality, which for the mole is the link between mass and number of particles and the physical quantity, *n* the amount of substance. Pekdağ and Azizoğlu (2013) also state that knowledge about the amount of substance is associated with the macroscopic level, in terms of mass and volume of gases, the submicroscopic level, in terms of the number of particles and at a symbolic level, with a chemical formula. According to the authors, it is therefore important to associate amount of substance at these three levels from a semantic perspective. They provide models that teachers can use to ensure they use the correct semantic expressions when teaching stoichiometry. This knowledge also goes beyond just TSPCK and understanding how the word amount contributes to the difficulties in teaching stoichiometry.

Knowledge of the historical development of the mole concept, and considering stoichiometry as part of a chemist's toolbox and not just a topic, encompasses more than just content knowledge. Knowledge of linking ideas that bridge the particulate prerequisite concepts with aspects of the mole concept, being able to discern the critical features of words with everyday meanings and scientific meanings and semantic considerations are also beyond just knowledge of LPK or WDT as part of a teachers' TSPCK. This knowledge is specific for the teaching of stoichiometry. Toerien (2017) refers to knowledge that includes topic content knowledge and the five TSPCK knowledge components as topic-specific knowledge for teaching, or TSKFT. It is speculated that the knowledge described here specifically for the effective teaching of stoichiometry is TSKFT and requires further investigation.

The TPK&S Model and Interaction of Knowledge Bases

The TPK&S model of teacher knowledge including PCK (Gess-Newsome, 2015) was part of the theoretical framework of this study and was used as an analytical framework for coding talk units in the planning and discussion meetings of the PLC. However, currently this model is being revised (Berry *et al.*, 2017). One of these revisions included a rotation of the model. This has been conceptualised as shown in Figure 8.6.

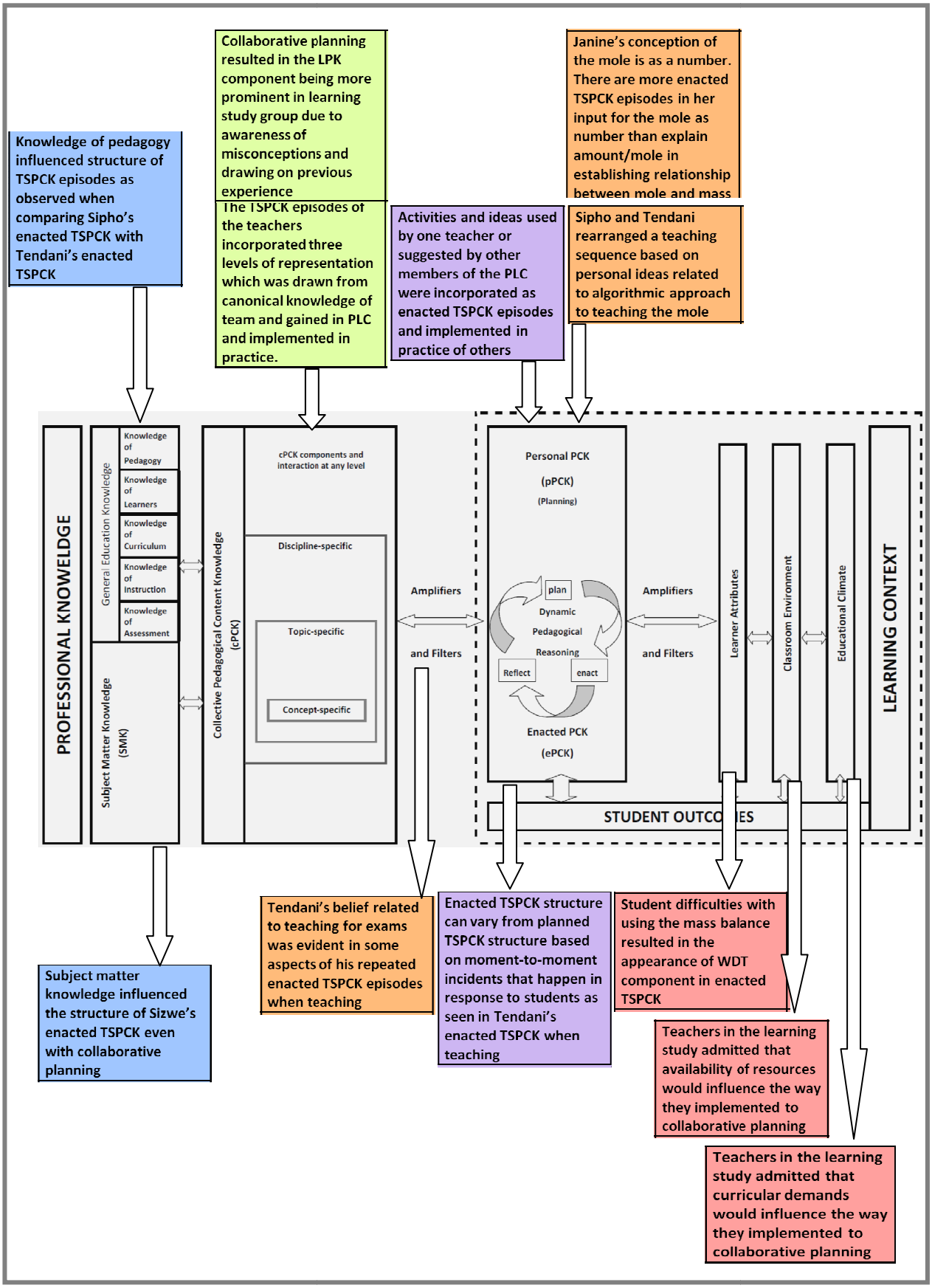


Figure 8.6: Links to findings in study with the TPK&S model

In this model the teacher in the centre of the model drawing on their personal knowledge when engaging in practice, or classroom enactment. Professional knowledge bases and contextual factors are found in concentric layers around the teacher and this has an impact on their personal knowledge and practice. Figure 8.6 illustrates the TPK&S model taking into account, that the teacher is the central feature in this model. Their personal knowledge, which is described in the TPK&S model as personal PCK, is drawn from the TSPK (or collective PCK), as was done in the learning study in planning the lesson, but clearly is modified when moving from the collective TSPCK evident in the PLC to plan the lesson to enacted TSPCK in the classroom. Content knowledge and pedagogical knowledge can influence enacted TSPCK (see blue boxes on Figure 8.6). The knowledge bases therefore influence what teachers might plan, and is on the one side of teacher reasoning. In this study, the plan was developed collaboratively and the narrative analysis revealed that content knowledge and pedagogical knowledge either enhanced or hindered enacted TSPCK. However, as with the study conducted by Toerien (2017), this study found no evidence of the backward flow from TSPCK impacting on the professional knowledge bases.

On the other hand, what happens in practice is that the enacted TSPCK is directly influenced by student attributes, in this case their ability to manipulate practical equipment. The participating teachers mentioned contextual factors, such as the availability of resources in the classroom and curricular demands, that would influence their classroom enactment (red blocks on Figure 8.6). These contextual factors influence teacher reasoning on what happens in the classroom, in teaching or with their enacted TSPCK. Although not investigated in this study, the students as an agency in the educational process are acknowledged and also act as filters and amplifiers (Gess-Newsome, 2015). As can be seen, the TPK&S model (see Chapter 2) has been rotated, with the teacher in the centre, the knowledge bases as one factor that influence personal knowledge on the right and contextual factors which also influence personal knowledge on the left (Rollnick & Mavhunga, 2017). Included on Figure 8.6 are references to specific observations made in this thesis, or aspects mentioned by teachers that would influence their implementation of the type of lesson developed through collaboration in the Learning Study. This study therefore provides empirical evidence that indicates how and why these components interact (Berry *et al.*, 2017).

This section has outlined this study's contribution to the TSPCK research community and argues for the need to use an agreed way of determining the platforms for TSPCK maps. This

section has also outlined how TSPCK event maps can be used to get an overall picture of the quality of teachers' TSPCK in a topic. Difficulties in stoichiometry have long been reported on in the literature (Dierks, 1981), and aspects of teacher knowledge required to effectively teach stoichiometry possibly support the idea of TSKFT but this is only conjecture and requires further investigation. Finally, evidence has been highlighted that speak to the possible interactions of the TPK&S model, which is currently under revision (Berry *et al.*, 2017). The remainder of this chapter looks at the recommendations, limitations of this study and reflection.

8.5. Recommendations

In Chapter 1, the context of this study was outlined in which concern was raised over the introduction of teaching stoichiometry in Grade ten in the new South African curriculum and the demands this could place on teachers who may not have taught this content. Based on the findings of this study, and in light of the problems indicated in Chapter 1, the following recommendations and suggestions for further study are made:

Measure Baseline PCK of Science Teachers in Stoichiometry

Artefacts that have been produced during this study are valid and reliable instruments that can be used to measure the quality of teachers' TSPCK and CK in stoichiometry. Since valid and reliable instruments to measure TSPCK in stoichiometry and stoichiometric CK have been developed, it is suggested that these instruments be administered on a larger scale to South African teachers, including Grade 10 Physical Sciences teachers. The advantage of paper-and-pencil TSPCK instruments for large groups is that they are easily administered (Morrison & Luttenegger, 2015). Such a baseline assessment could also help inform the interventions to address the need to improve learning in this topic.

Capture and Portray TSPCK of Teachers' with Good quality TSPCK

The qualitative analysis of the TSPCK instruments indicated that only a small number of teachers sampled teach stoichiometry in a way that can be described as conceptually adequate. Therefore, teachers with exemplary PCK that teach conceptually can be identified from those respondents who complete the instrument during the baseline measurement of PCK in stoichiometry. Generally, it would be expected that teachers with exemplary PCK have good content knowledge, which would be determined by the CK Achievement

instrument, and have many years of experience in teaching stoichiometry. The PCK of these experienced teachers with exemplary PCK can be elicited through CoRes, which provide an overview of the content when teaching stoichiometry, and PaP-eRs that capture teaching practice (Loughran *et al.*, 2012; Mulhall *et al.*, 2003). By eliciting these experienced teachers' TSPCK in stoichiometry, this knowledge can be shared with other teachers in an attempt to improve learning in stoichiometry. Eliciting PCK from teachers identified with exemplary PCK could open two possible avenues for further research. The first is to report on the representation of PCK in stoichiometry through PaP-eRs to portray it to other teachers and broaden the work done by Loughran *et al.* (2012)

Developing TSPCK in Professional Learning Communities and Learning Studies

The results of this study have indicated that the engagement in a Learning Study as part of a PLC has the potential to not only develop teachers' TSPCK (Nilsson, 2014) but also improve classroom enactment. The formation of such PLCs is in line with the strategic plan for teacher development in South Africa (Department of Basic Education & Department of Higher Education & Training, 2011b). The results of this study indicated that working collaboratively in a PLC that engages with practice has the potential to improve the quality of teachers and teaching. Key to achieving this outcome, however, is collaboration, which includes collaboration with Higher Education institutions. Such communities, which include members in science teacher education, need to focus on inquiry as a tool for learning and development (Jaworski, 2008). Such partnerships, however, do need to consider the economic costs related to such partnerships. Sufficient funding is required for the implementation of forming Professional Learning Communities (Department of Basic Education & Department of Higher Education & Training, 2011a).

Developing Shared Practices in the TSPCK Research Community

Those involved in the research of teachers' TSPCK development and/or investigating it in classroom enactment are part of a community of practice, and it is therefore essential to develop a shared repertoire of communal resources (Lave & Wenger, 1998). In this study, these communal resources, such as the adapted CoRe, the use of pictorial maps to show the interactions of TSPCK components and the TSPCK model were all used. It is recommended that further research on TSPCK component interactions use the lesson elements as platforms.

Extending the TSPCK Practice Rubric to TSPCK Event Maps

The categories of quality TSPCK event maps shown in Figure 8.5 are only suggestions based on the categories in the classroom enactment rubric (Miheso & Mavhunga, 2018). Such category development would need to be validated. Such categorisation of the TSPCK event maps could be added to the enactment rubric. This would then allow the rubric to not only provide an overview of the quality categories in a TSPCK episode, but also provide an overall single score of the quality of TSPCK (Miheso & Mavhunga, 2018). It is suggested that the further development of the TSPCK enactment rubric be undertaken, in order to be able to assess the quality of teachers' TSPCK at a concept, big idea level and at a topic level. This could be a fruitful avenue for further study in the field of TSPCK, as it provides a means to determine the overall quality of enacted TSPCK in a topic.

The Conceptualisation of the Mole and South African Curriculum Support Materials

In the South African curriculum documents, learners are expected to understand that the mole is the SI unit for the amount of substance (Department of Basic Education, 2011a). However, from the qualitative analysis of the respondents' responses in Phase I of this study, it was evident that half of the respondents viewed the mole as a number and many referred to the symbol for amount of substance, *n*, as its unit 'the mole' or 'number of moles'. Packer (1988) strongly feels that this contributes to the problems learners have in solving stoichiometric problems, and Staver and Lumpe (1993) and Strömdahl *et al.* (1994) argue that a conception of the mole that is consistent with the SI definition, is essential for effective teaching in stoichiometry. Textbook writers need to ensure when developing learning materials that they conform to the curriculum documents, and take note of the arguments relating to the conception of the mole in order to avoid perpetuating misconceptions. The continued dismal performance in stoichiometry could be due to the way the mole is conceptualised by teachers, and their approach to teaching stoichiometry based on their conceptualisation of the mole and the learner support materials they use (Department of Basic Education, 2013, 2014). The question of whether learner performance in stoichiometry could improve as teachers apply TSKFT with the correct conceptualisation of the mole needs to be investigated.

This section has aimed at providing recommendations and suggestions for further study. The design of valid instruments can contribute to the baseline assessment of teachers' TSPCK and

CK in stoichiometry. Based on the improvement of the teachers' TSPCK, a Learning Study as a form of professional learning, has the potential to improve teacher knowledge and classroom enactment if the guidelines for implementation of the strategic plan for teacher development, including time and funding, are followed (Department of Basic Education & Department of Higher Education & Training, 2011b).

8.6. Limitations of the Study

In qualitative research, the researcher becomes the instrument for research. Since a mixed methods study has a qualitative component, it will largely rely on the personal activities and outlook of the researcher. To avoid this, the methods were fully described in Chapter 3, and aspects related to data analysis were included in the relevant chapters. In addition, any assumptions related to the interpretations of participants in the Learning Study, or of the observed lessons were included, to mitigate any bias or inadequacy. Due to the fairly small sample size in Phase I, the selection of cases from this sample for Phase II and the focus on one topic in chemistry, namely stoichiometry, this study will be unable to claim generalisability. The selection of the teachers for the comparison group was done because they all taught at the same school for convenience in terms of location. Although there was a good pairing for most of the teachers, a more valid comparison could have been made by matching Sipho with Geraldine, whose TSPCK scores were similar.

In addition, the three teachers involved in the Learning Study were participating as part of their research project for a post-graduate degree. This would have influenced their willingness to participate. The same level of commitment might not have been there without this additional motivation. The teachers who participated in this study also indicated that curriculum demands would impact on their ability to participate in such long term professional learning activities. It is therefore vital that if teachers form PLCs, their commitment to the process is required. However forming PLCs within high schools is also considered challenging for a number of reasons (McLaughlin & Talbert, 2007). These challenges include, firstly the structural organisation of high schools ranging from the work structure of high school teachers, involving administrative tasks, and planning for multiple course preparations, which leaves little time for collaboration. Secondly, the professional culture within high schools, where the traditional norm is teaching subjects rather than students, often hinders teachers working collaboratively. Another barrier to increased

collaboration within schools is that teachers often have differing pedagogical orientations, and the cultural norm in teaching is individualism, where teachers work in isolation and privacy (A. Mitchell, 1997). External contexts, such as high stakes accountability systems and external examinations also impact on high school teachers' incentive to spend time critically reflecting on practice, collaborating with colleagues in the school, or investing in professional growth.

Finally, since PCK is considered personal and therefore unique to a particular teacher, based on their teaching context and the school where they are employed, it could therefore only represent those teachers who participated in the study. However, this study is expected to contribute substantially to the body of knowledge on the development of PCK, especially in practising teachers and the enactment of planned PCK into practice, particularly related to the construct of topic-specific PCK. Student outcomes feed back into classroom practice, hence the need to administer the pre-lesson and post-lesson diagnostic tests to learners. However, this study is limited to investigating TSPCK development and enactment in practice, without investigating the possible impact on student outcomes of collaborative planning. Due to the many factors that filter and amplify learner achievement, without an extensive exploration the impact of teachers' involvement in a Learning Study between classroom enactment and student outcomes any variations in student outcomes on these diagnostic tests will be based on conjecture based on the participating teachers' experience.

8.7. Personal Reflections

Reflecting on Research Methodology

Initially, this study began as a Master's research project to design and validate an instrument to determine the quality of teachers' TSPCK in stoichiometry. This represents part of Phase I of this study and it was here that I was first introduced to mixed methods. Phase II of the study also used a mixed methods design. A mixed methods study is more than just collecting both qualitative and quantitative data; it is the integration of this data in both the analysis and reporting. As with qualitative studies, there are times that the methods used need to be changed. In Phase I, there was a need to do document analysis of the curriculum which was not initially planned. When examining teacher responses to the items, this evolved into a constant comparison analysis, a quantitative method that was followed by a qualitative method, cluster analysis, to confirm teaching profiles related to determining the quality

categories for teaching stoichiometry. With Phase II, due to the small sample size, statistically sound methods were actively sought to do the quantitative analysis to keep with the tradition of analysing data both qualitatively and quantitatively.

Reflecting on the Professional Learning Community

When convening the PLC, the participating teachers and their respective supervisors were brought together based on a common interest, that of completing the research component of the M.Sc programme, and the potential to work together for a common end, researching the impact of collaboration on teachers' PCK development (Dooner *et al.*, 2008). On one hand, two different but interrelated communities of practice with distinct identities, based on their competence and experience as science teacher educators, or Physical Science educators teaching in schools, were being brought together as part of a larger social system (Wenger, 2000, 2010). On the other hand, as part of a larger social system, we also represented a community of practice of science education researchers, with myself as the researcher and the supervisors as core members of the community and the participating teachers on the periphery of the community (Wenger, 1998b, 2010). The course on research methods and design in science education being completed by the teacher participants was developing their practice as researchers and developing a shared repertoire of resources (Wenger, 1998a, 2011). This included developing the conceptual artefacts, related to science education research, in order to produce the physical artefacts, such as a research proposal, ethics application and seminar presentation through reification (Wenger, 2010, 2011). Since the combination of course work for the M.Sc is decided each year, missing from the participating teachers' repertoire, and a key principle in which research undertaken by the supervisors and my own research in Phase I of this study drew on, was the construct of topic-specific PCK. The conceptual artefacts such as the components of TSPCK and the physical artefacts, such as CoRes, needed to be introduced to the participating teachers in our joint enterprise for the effective mutual engagement of the community (Wenger, 1998a, 2010, 2011).

Reflecting on Teacher Knowledge

While completing this study, the consensus model of teacher knowledge was negotiated by the researcher community involved in investigating PCK (Gess-Newsome, 2015). Currently the consensus model is being revised (Berry *et al.*, 2017). As an individual, whose passion has always been teaching and education, the revised model confirms what dedicated teachers

experience. On the one end is the knowledge a teacher has about effective teaching and learning, whereas on the other hand there are the limitations of contextual factors that a teacher experiences. What happens in the class is a balance that works and this study has provided some empirical evidence of how these two aspects inform classroom enactment. The topic-specific model of TSPCK is a valuable construct that can improve the teaching of topics and that it can be developed through participation in PLCs for particular topics is exciting. However, in the Learning Study our PLC neglected aspects of knowledge of students, pedagogy and content that also need to be focused on. With the topic of stoichiometry there were also other aspects of knowledge that cannot be quite categorised. This begs the question: is there TSKFT that is required by teachers? As Toerien (2017) noted, this was a new construct developed in her study. The merit of this construct needs to be explored.

Reflecting on Personal Learning

One of the advantages of this study is that it has contributed to the development of my own PCK in stoichiometry. The review of the literature into learner misconceptions and difficulties with stoichiometry broadened my knowledge of learner prior knowledge. The preparation in terms of developing a CoRe, assisted in being able to articulate my PCK, and the framing of the big ideas helped clarify the central ideas learners need to understand when learning stoichiometry. The process of brainstorming and framing the big ideas with the reference team assisted me personally in meaningful engagement with big ideas (Rollnick & Mavhunga, 2015). In addition, based on the literature review regarding conceptual teaching strategies, a teaching model for teaching stoichiometry, starting with macroscopic observable properties through practical experimentation, before explaining these using submicroscopic properties and symbolic representation, has been framed in my own practice. This has all contributed to working towards transforming my content knowledge into forms more accessible to my learners and developing my own TSPCK in stoichiometry. This experience could be shared during the Learning Study. The teachers involved also brought interesting ideas and examples that were incorporated into the final lesson (see Appendix 19) and that contributed to my learning. One aspect that has also been cemented in my thinking is that stoichiometry should not be approached as just a topic to teach in chemistry. Evans *et al.* (2006) highlight that stoichiometry is part of a chemist's 'toolbox' and as such is used in all aspects of their work and as such stoichiometric concepts can be revised in all sections of

chemistry. This idea has also been proposed by the external examiners when reporting on students' performance in the matric examinations (Department of Basic Education, 2017).

In Closing

I have always been passionate about education. Firstly, as a teacher in the classroom and striving to make science both interesting and accessible to my students, and secondly as an early career researcher researching teachers' TSPCK. In conducting this research, as a researcher collaborating with teachers to improve the teaching of stoichiometry these two aspects coalesced. The findings related to the impact of collaborating with teachers in a Learning Study as part of a Professional Learning Community are exciting. The next step would be to determine if learning in the topic of stoichiometry can be improved through such collaboration.

References

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

Adamson, B., & Walker, E. (2011). Messy collaboration: Learning from a Learning Study. *Teaching & Teacher Education, 27*(1), 29-36.

Agung, S., & Schwartz, M. S. (2007). Students' understanding of conservation of matter, stoichiometry and balancing equations in Indonesia. *International Journal of Science Education, 29*(13), 1679-1702.

Ainley, D. (1991). Mole catchers? *Education in Chemistry, 28*(1), 18 - 19.

Akın, F. N., & Uzuntiryaki-Kondakci, E. (2018). The nature of the interplay among components of pedagogical content knowledge in reaction rate and chemical equilibrium topics of novice and experienced chemistry teachers. *Chemistry Education Research and Practice, 19*(1), 80-105.

Akiri, A. A., & Ugborugbo, N. M. (2009). Teachers' effectiveness and students' academic performance in public secondary schools in Delta State, Nigeria. *Studies on Home and Community Science, 3*(2), 107-113.

Aleksandrov, Y. I. (1989). The mole: Myths and reality. *Measurement Techniques, 32*(1), 82 - 87.

Allsop, R. (1977). The place and importance of the mole in school Chemistry courses. *Physics Education, 12*(5), 285 - 288.

Alshenqeeti, H. (2014). Interviewing as a data collection method: A critical review. *English Linguistics Research, 3*(1), 39-45.

Anney, V. N., & Hume, A. C. (2014). Enhancing untrained science teachers' pedagogical content knowledge (PCK) in developing countries through teachers' professional learning communities (PLCs). *International Journal of Development and Sustainability, 3*(8), 1709-1744.

Arcidiacono, G. (2014). Statistics calculator: Correlation coefficient Alcula.com Retrieved from http://www.alcula.com/calculators/statistics/correlation-coefficient

Ashcraft, N. (2015). *Lesson planning*. Annapolis Junction, Maryland, USA: TESOL Press.

Avalos, B. (1998). School-based teacher development the experience of teacher professional groups in secondary schools in Chile. *Teacher & Teacher Education, 14*(3), 257-271. doi: http://dx.doi.org/10.1016/S0742-051X(97)00040-1

Aydin, 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*(4), 615-624. doi: 10.1039/C3RP00095H

Aydin, S., Demirdogen, B., Nur Akin, F., Uzuntiryaki-Kondakci, E., & Tarkin, A. (2015). The nature and development of interaction among components of pedagogical content knowledge in practicum. *Teaching & Teacher Education, 46*, 37-50. doi: http://dx.doi.org/10.1016/j.tate.2014.10.008

Aydin, S., Friedrichsen, P. M., Bozc, Y., & Hanuscinb, D. L. (2014). Examination of the topic-specific nature of pedagogical content knowledge in teaching electrochemical cells and nuclear reactions. *Chemical Education Research and Practice, 15*, 658-674.

Baird, J. R., Fensham, P. J., Gunstone, R. F., & White, R. T. (1991). The importance of reflection in improving science teaching and learning. *Journal of research in science teaching, 28*(2), 163-182. doi: 10.1002/tea.3660280207

Ball, D. L., Thames, M. H., & Phelps, G. (2008). Content knowledge for teaching what makes it special? *Journal of Teacher Education, 59*(5), 389-407.

Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York, New Youk: Freeman.

Barter, C., & Renold, E. (1999). The use of vignettes in qualitative research. *Social research update, 25*(9), 1-6.

Baxter, J. A., & Lederman, N. G. (1999). Assessment and measurement of pedagogical content knowledge. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content*

knowledge: The Construct and its Implications for Science Education (pp. 147-161). Dordrecht, the The Netherlands Springer/Kluwer Academic Publishers.
Bell, J. (2005). *Doing your own research project: A guide for first-time researchers in education, health and social science* (4th ed.). Berkshire, England: Open University Press, McGraw-Hill Education.
Berliner, D. C. (2001). Learning about and learning from expert teachers. *International Journal of Educational Research, 35*(5), 463-482. doi: http://dx.doi.org/10.1016/S0883-0355(02)00004-6
Berry, A., Nilsson, P., Van Driel, J. H., & Carlson, J. (2017). *Analysing science teachers'pedagogical content knowledge: A report on the second PCK summit*. Paper presented at the 12th Conference of the European Science Education Research Association, Dublin, Republic of Ireland.
Bertram, A. (2014). CoRes and PaP-eRs as a strategy for helping beginning primary teachers develop their pedagogical content knowledge. *Educación Química, 25*(3), 292-303.
Bishop, K., & Denley, P. (2007). *Learning science teaching: Developing a professional knowledge base*. Berkshire, England: Open University Press, McGraw-Hill Education.
Blankstein, A. M. (1996). Why TCM can't work – and a school where it did. *The Education Digest, 62*(1), 27-30.
Blonder, R., Benny, N., & Jones, M. G. (2014). Teaching self-efficacy of science teachers. In R. Evans, J. Luft, C. M. Czerniak, & C. Pea (Eds.), *The role of science teachers' beliefs in international classrooms* (pp. 3-15). Rotterdam, Netherlands: Sense Publishers.
Boeije, H. (2002). A purposeful approach to the constant comparative method in the analysis of qualitative interviews. *Quality & quantity, 36*(4), 391-409.
Bolam, R., McMahon, A., Stoll, L., Thomas, S., Wallace, M., Greenwood, A., Hawkey, K., *et al.* (2005). *Creating and sustaining effective professional learning communities*. University of Bristol, Bristol, United Kingdom: Department for Education and Skills London.
Bolam, R., Stoll, L., & Greenwood, A. (2007). The involvement of support staff in professional learning communities. In L. Stoll & K. Seashore Louis (Eds.), *Professional Learning Communities: Divergence, Depth & Dilemmas* (pp. 17-29). Berkshire, England: Open University Press, McGraw-Hill Education.
Bond-Robinson, J. (2005). Identifying pedagogical content knowledge (PCK) in the Chemistry laboratory. *Chemistry Education Research and Practice, 6*(2), 83-103.
Bond, T. G., & Fox, C. M. (2001). *Applying the Rasch model: Fundamental measurement in the human science*. Mahwah, New Jersey: Lawrence Erlbaum Associates, Inc.
Boone, W. J., & Rogan, J. (2005). Rigour in quantitative analysis: The promise of Rasch analysis techniques. *African Journal of Research in Mathematics, Science & Technology Education, 9*(1), 25-38.
Boone, W. J., & Scantlebury, K. (2006). The role of Rasch analysis when conducting science education research utilizing multiple-choice tests. *Science Education, 90*(2), 253-269.
Boone, W. J., Staver, J., & Yale, M. S. (2014). *Rasch analysis in the human sciences*. Dordrecht, The Netherlands: Springer.
Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. *Educational Researcher, 33*(8), 3-15. doi: 10.3102/0013189x033008003
Borowski, A., Carlson, J., Fischer, H., Henze, I., Gess-Newsome, J., Kirschner, S., & Van Driel, J. H. (2012). Different models and methods to measure teachers' pedagogical content knowledge. In C. Bruguière, A. Tiberghien, & P. Clément (Eds.), *E-Book Proceedings of the ESERA 2011 Conference: Science learning and Citizenship.* (Vol. 13: In-service science teacher education; (co-eds. J. Viiri & D. Couso),, pp. 25-36). Lyon, France: European Science Education Research Association.
Botha, E. M. (2012). Turning the tide: creating Professional Learning Communities (PLC) to improve teaching practice and learning in South African public schools. *Africa Education Review, 9*(2), 395-411. doi: 10.1080/18146627.2012.722405
BouJaoude, S., & Barakat, H. (2000). Secondary school students' difficulties with stoichiometry. *School Science Review, 81*(296), 91-98.

BouJaoude, S., & Barakat, H. (2003). Students' problem solving strategies in stoichiometry and their relationships to conceptual understanding and learning approaches. *Electronic Journal of Science Education, 7*(3). Retrieved from: http://ejse.southwestern.edu/article/view/7709/0

Briscoe, C., & Peters, J. (1997). Teacher collaboration across and within schools: Supporting individual change in elementary science teaching. *Science Education, 81*(1), 51-65.

Brodie, K. (2004). Re-thinking teachers' mathematical knowledge : a focus on thinking practices : research article. *Perspectives in Education, 22*(1), 65-80. Retrieved from: http://reference.sabinet.co.za/webx/access/electronic_journals/persed/persed_v22_n1_a7.pdf

Brodie, K. (2011). *Professional learning communities and teacher change*: HTW Dresden.

Brodie, K. (2013). The power of professional learning communities. *Education as Change, 17*(1), 5-18.

Brodie, K. (2014). Learning about learner errors in professional learning communities. *Educational Studies in Mathematics, 85*(2), 221-239.

Brodie, K., & Shalem, Y. (2011). Accountability conversations: mathematics teachers' learning through challenge and solidarity. *Journal of Mathematics Teacher Education, 14*(6), 419-439. doi: 10.1007/s10857-011-9178-8

Brophy, J. E., & Good, T. L. (1986). Teacher behaviour and student achievement. In M. C. Wittrock (Ed.), *Handbook of Research on Teaching* (3rd ed., pp. 328-375). New York, New York, USA: Macmillan Publishing Company.

Buysse, V., Sparkman, K. L., & Wesley, P. W. (2003). Communities of practice: Connecting what we know with what we do. *Exceptional Children, 69*(3), 263-277.

Bybee, R. W. (2009). *The BSCS 5E instructional model and 21st century skills*. Paper presented at the Education Workshop on Exploring the Intersection of Science Education and the Development of 21st Century Skills, Washington, DC.

Campbell, J. L., Quincy, C., Osserman, J., & Pedersen, O. K. (2013). Coding in-depth semistructured interviews:Problems of unitization and intercoder reliability and agreement. *Sociological Methods & Research, 42*(3), 294-320. doi: 10.1177/0049124113500475

Canpolat, N., Pınarbaşı, T., Bayrakçeken, S., & Geban, O. (2006). The conceptual change approach to teaching chemical equilibrium. *Research in Science & Technological Education, 24*(2), 217-235.

Carlson, J., & Daehler, K. R. (in press). The revised consensus model of Pedagogical Content Knowledge. In A. Hume, R. Copper, & A. Borowski (Eds.), *Repositioning PCK in Teachers' Professional Knowledge*. Abingdon, United Kingdom: Routledge.

Carlson, J., Gess-Newsome, J., Gardner, L., Wilson, C. D., & Stuhlsatz, M. A. M. (2010). *How professional development based on educative materials affects teacher pedagogical content knowledge (PCK), classroom practice, and student achievement*. Paper presented at the Annual meeting of the American Educational Research Association, Denver, Colorado, USA.

Carlson, J., Stokes, L., Helms, J., Gess-Newsome, J., & Gardner, A. (2015). The PCK summit: A process and structure for challenging current ideas, provoking future work, and considering new directions. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-Examining Pedagogical Content Knowledge in Science Education* (pp. 14 - 27). Abington, UK: Routledge.

Carter, K. (1990). Teachers' knowledge and learning to teach. In W. R. Houston (Ed.), *Handbook of research on teacher education* (pp. 291-310). New York, New York, USA: MacMillan.

Carter, K. (1993). The Place of Story in the Study of Teaching and Teacher Education. *Educational Researcher, 22*(1), 5-18. doi: 10.2307/1177300

Cervellati, R., Montuschi, A., Perugini, D., Grimellini-Tomasini, N., & Balandi, B. P. (1982). Investigation of secondary school students' understanding of the mole concept in Italy. *Journal of Chemical Education, 59*(10), 852 - 856.

Chalmers, L., & Keown, P. (2006). Communities of practice and professional development. *International Journal of Lifelong Education, 25*(2), 139-156. doi: 10.1080/02601370500510793

Chan, K. K. H., & Yung, B. H. W. (2015). On-site pedagogical content knowledge development. *International Journal of Science Education, 37*(8), 1-33.

Chan, K. K. H., & Yung, B. H. W. (2017). Pedagogical content knowledge development in experienced biology teachers in their first attempts at teaching a new topic. In J. Yeo, T. W. Teo, & K.-S. Tang (Eds.), *Science Education Research and Practice in Asia-Pacific and Beyond* (pp. 197-214). Singapore: Springer.

Chandrasegaran, A., Treagust, D. F., Waldrip, B. G., & Chandrasegaran, A. (2009). Students' dilemmas in reaction stoichiometry problem solving: deducing the limiting reagent in chemical reactions. *Chemistry Education Research and Practice, 10*(1), 14-23.

Chang, A. (n.d.). Computer program to calculate Cohen and Fleiss kappa: StatsToDo.com. Retrieved from https://www.statstodo.com/CohenKappa_Pgm.php#Fleiss'sKappafromratingscores

Chokshi, S., & Fernandez, C. (2004). Challenges to importing Japanese lesson study: Concerns, misconceptions, and nuances. *The Phi Delta Kappan, 85*(7), 520.

Clark, C. M., & Peterson, P. L. (1986). Teachers' thought processes. In M. C. Wittrock (Ed.), *Handbook of Research on Teaching* (3rd ed., pp. 255-296). New York, New York, USA: Macmillan Publishing Company.

Clement, J. J. (1998). Expert novice similarities and instruction using analogies. *International Journal of Science Education, 20*(10), 1271-1286.

Clermont, C. P., Borko, H., & Krajcik, J. S. (1994). Comparative study of the pedagogical content knowledge of experienced and novice chemical demonstrators. *Journal of research in science teaching, 31*(4), 419-441.

Clynick, T., & Lee, R. (2004). *From laggard to world class: Reforming maths and science education in South Africa's schools*. Johannesburg, Guateng, South Africa: Centre for Development and Enterprise.

Cochran, K. F. (1997). Pedagogical content knowledge: Teachers' integration of subject matter, pedagogy, students, and learning environments. *Research matters to the Science Teacher, 14*, 97-102.

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, Chicago, Illinois.

Cohen, L., Manion, L., & Morrison, K. (2007). *Research methods in education* (6th ed.). New York, New York, USA: Routledge.

Cole, A. L. (1989). Researcher and Teacher: partners in theory building. *Journal of Education for Teaching, 15*(3), 225-237. doi: 10.1080/0260747890150304

Conover, W. J. (1980). *Practical nonparametric statistics* (2nd ed.). New York, New York: John Wiley & Sons, Inc.

Corrigan, D., Gunstone, R., & Dillon, J. (2011). Approaches to considering the professional base of science teachers. In D. Corrigan, R. Gunstone, & J. Dillon (Eds.), *The Professional Knowledge Base of Science Teaching* (pp. 1 - 11). Dordrecht, The The The Netherlands: Springer Science & Business Media.

Creswell, J. W. (2012). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research* (4th Ed.). Boston, Massachusetts: Pearson Education, Inc.

Creswell, J. W., & Garrett, A. L. (2008). The" movement" of mixed methods research and the role of educators. *South African Journal of Education, 28*(3), 321-333.

Creswell, J. W., & Tashakkori, A. (2007). Editorial: Developing publishable mixed methods manuscripts. *Journal of Mixed Methods Research, 1*(2), 107-111.

Cronk, B. C., & West, J. L. (2002). Personality research on the Internet: A comparison of Web-based and traditional instruments in take-home and in-class settings. *Behavior Research Methods, Instruments, & Computers, 34*(2), 177-180. doi: 10.3758/bf03195440

Daehler, K. R., & Shinohara, M. (2001). A complete circuit is a complete circle: Exploring the potential of case materials and methods to develop teachers' content knowledge and pedagogical content knowledge of science. *Research in Science Education, 31*(2), 267-288.

Dahsah, C., & Coll, R. K. (2007). Thai Grade 10 and 11 students' conceptual understanding and ability to solve stoichiometry problems. *Research in Science & Technological Education, 25*(2), 227-241. doi: 10.1080/02635140701250808

Darling-Hammond, L., & Richardson, N. (2009). Research review/teacher learning: What matters. *Educational Leadership, 66*(5), 46-53.
Davidowitz, B., & Chittleborough, G. (2009). Linking the macroscopic and sub-microscopic levels: Diagrams. In J. K. Gilbert & D. Treagust (Eds.), *Multiple representations in chemical education* (pp. 169-191). Dordrecht, Netherlands: Springer.
Davidowitz, B., & Rollnick, M. (2011). What lies at the heart of good undergraduate teaching? A case study in organic Chemistry. *Chemistry Education Research and Practice, 12*(3), 355-366.
Dawes, J. (2008). Do data characteristics change according to the number of scale points used. *International journal of market research, 50*(1), 61-77.
De Jong, O., Van Driel, J. H., & Verloop, N. (2005). Preservice teachers' pedagogical content knowledge of using particle models in teaching Chemistry. *Journal of research in science teaching, 42*(8), 947-964.
Department of Basic Education. (2011a). *Curriculum and assessment policy statement grades 10 – 12: Physical Sciences.* . Pretoria, Gauteng, South Africa: Department of Basic Education.
Department of Basic Education. (2011b). National senior certificate examination 2010: National report on learner performance in selected subjects. Pretoria, Gauteng, South Africa: Department of Basic Education.
Department of Basic Education. (2013). National Senior Certificate examination national diagnostic report on learner performance 2012. Pretoria, Gauteng, South Africa: Department of Basic education.
Department of Basic Education. (2014). 2013 National Senior Certificate examination national diagnostic report. Pretoria, Gauteng, South Africa: Department of Basic Education.
Department of Basic Education. (2016). National senior certificate examination 2015 diagnostic report. Pretoria, Gauteng, South Africa: Department of Basic Education.
Department of Basic Education. (2017). National senior certificate examination 2016 diagnostic report. Pretoria, Gauteng, South Africa: Department of Basic Education.
Department of Basic Education, & Department of Higher Education & Training. (2011a). Integrated strategic planning framework for teacher education and development in South Africa 2011 – 2025: Technical report. Pretoria, Gauteng, South Africa: The Departments of Basic Education & Higher Education and Training.
Department of Basic Education, & Department of Higher Education & Training. (2011b). *Integrated strategic planning framework for teacher education and development in South Africa, 2011–2025*. Pretoria, Gauteng, South Africa: The Departments of Basic Education and Higher Education and Training.
Department of Education. (2003). *National curriculum statement grades 10 - 12 (general): Physical Sciences.* . Pretoria, Gauteng, South Africa: Department of Education.
Department of Education. (2006). *The National Policy Framework for Teacher Education and Development in South Africa*. Pretoria, Gauteng, South Africa: Department of Education.
Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher, 38*(3), 181-199.
Desimone, L. M., Porter, A. C., Garet, M. S., Yoon, K. S., & Birman, B. F. (2002). Effects of professional development on teachers' instruction: Results from a three-year longitudinal study. *Educational evaluation and policy analysis, 24*(2), 81-112.
DeToma, R. P. (1994). Symbolic algebra and stoichiometry. *Journal of Chemical Education, 71*(7), 568 - 570.
Dierks, W. (1981). Teaching the mole. *European Journal of Science Education, 3*(2), 145-158.
Dierks, W., Weninger, J., & Herron, J. D. (1985). Mathematics in the Chemistry classroom. Part 1. The special nature of quantity equations. *Journal of Chemical Education, 62*(10), 839.
Doll, P. A., & Jacobs, K. W. (1988). The exit interview for graduating seniors. *Teaching of Psychology, 15*(4), 213-214.
Dooner, A.-M., Mandzuk, D., & Clifton, R. A. (2008). Stages of collaboration and the realities of professional learning communities. *Teacher & Teacher Education, 24*(3), 564-574.

Doyle, W. (1986). Classroom organization and management. In M. C. Wittrock (Ed.), *Handbook of Research on Teaching* (3rd ed., pp. 392-431). New York, New York, USA Macmillan Publishing Company.
Drechsler, M., & Van Driel, J. H. (2008). Experienced teachers' pedagogical content knowledge of teaching acid–base Chemistry. *Research in Science Education, 38*(5), 611-631.
DuFour, R. (2004). What is a" professional learning community"? *Educational Leadership, 61*(8), 6-11.
Duit, R., & Treagust, D. F. (2003). Conceptual change: a powerful framework for improving science teaching and learning. *International Journal of Science Education, 25*(6), 671-688.
Duncan, I., & Johnstone, A. (1973). The mole concept. *Education in Chemistry, 10*(6), 213-214.
Earl, L. M., & Katz, S. (2006). *How networked learning communities work*. Melbourne, Victoria, Australia: Centre for Strategic Education.
Elbaz-Luwisch, F., & Orland-Barak, L. (2013). From teacher knolwedge to teacher learning in community: Transformations of theory and practice. In C. J. Craig, P. C. Meijer, & J. Broeckmans (Eds.), *From Teacher Thinking to Teachers and Teaching: The Evolution of a Research Community* (pp. 97-113). Bingley, UK: Emerald Group Publishing Ltd.
Essien, A., & Oyoo, S. O. (2016). Masters of science (M Sc) in science education: Programme information. School of Education, University of the Witwatersrand, Johannesburg South Africa: Marang Centre for Maths and Science Education.
Evans, K. L., Leinhardt, G., Karabinos, M., & Yaron, D. (2006). Chemistry in the field and Chemistry in the classroom: A cognitive disconnect? *Journal of Chemical Education, 83*(4), 655 - 661.
Evans, K. L., Yaron, D., & Leinhardt, G. (2008). Learning stoichiometry: a comparison of text and multimedia formats. *Chemistry Education Research and Practice, 9*(3), 208-218.
Even, R. (1993). Subject-matter knowledge and pedagogical content knowledge: Prospective secondary teachers and the function concept. *Journal for research in mathematics education, 24*(2), 94-116.
Fach, M., de Boer, T., & Parchmann, I. (2007). Results of an interview study as basis for the development of stepped supporting tools for stoichiometric problems. *Chemistry Education Research and Practice, 8*(1), 13-31. doi: 10.1039/B6RP90017H
Falk, A. (2012). Teachers learning from professional development in elementary science: Reciprocal relations between formative assessment and pedagogical content knowledge. *Science Education, 96*(2), 265-290.
Fang, S.-C., Hart, C., & Clarke, D. (2014). Unpacking the meaning of the mole concept for secondary school teachers and students. *Journal of Chemical Education, 91*(3), 351-356. doi: 10.1021/ed400128x
Fang, S.-C., Hart, C., & Clarke, D. (2015). Redefining the mole: the perspective of teaching and learning. *Accreditation and quality assurance, 20*(3), 215-217. doi: 10.1007/s00769-014-1102-3
Fenstermacher, G. D. (1986). Philosophy of research on teaching: Three aspects. In M. Wittrock (Ed.), *Handbook of Research on Teaching* (3rd ed., pp. 37-49). New York, New York, USA: Macmillan Publishing Company.
Fernandez, C. (2002). Learning from Japanese approaches to professional development the case of lesson study. *Journal of Teacher Education, 53*(5), 393-405.
Fernandez, C. (2005). Lesson study: A means for elementary teachers to develop the knowledge of mathematics needed for reform-minded teaching? *Mathematical thinking and learning, 7*(4), 265-289.
Fernandez, C., & Chokshi, S. (2002). A practical guide to translating lesson study for a US setting. *The Phi Delta Kappan, 84*(2), 128 - 134
Field, J. C., & Latta, M. M. (2001). What constitutes becoming experienced in teaching and learning? *Teacher & Teacher Education, 17*(8), 885-895. doi: http://dx.doi.org/10.1016/S0742-051X(01)00038-5
Figueira, A. R., Coch, J., & Zeplca, M. (1988). Teaching stoichiometry. *Journal of Chemical Education, 65*(12), 1060 - 1061.

Finlay, L. (2002). Negotiating the swamp: the opportunity and challenge of reflexivity in research practice. *Qualitative Research, 2*(2), 209-230. doi: 10.1177/146879410200200205
Fives, H., & Buehl, M. M. (2010). Examining the factor structure of the teachers' sense of efficacy scale. *The journal of experimental education, 78*(1), 118-134.
Floden, R. E. (2001). Research on the effects of teaching: A continuing model for research on teaching. In V. Richardson (Ed.), *Handbook of Research on Teaching* (4th ed., pp. 3-16). Washington. D.C., USA: American Educatinal Research Association.
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.
Foulger, T. (2005). Innovating professional development standards: A shift to utilize communities of practice. *Essays in Education, 14*. Retrieved from: http://www.usca.edu/essays/vol142005/foulger.pdf
Fraley, C., & Raftery, A. E. (1998). How many clusters? Which clustering method? Answers via model-based cluster analysis. *The computer journal, 41*(8), 578-588.
Frazer, M., & Servant, D. (1986a). Aspects of stoichiometry a wider view. *Education in Chemistry, 23*(5), 138-140.
Frazer, M., & Servant, D. (1986b). Aspects of stoichiometry titration calculations. *Education in Chemistry, 23*(2), 54-56.
Freelon, D. (2017). ReCal OIR. Retrieved from http://dfreelon.org/utils/recalfront/
Friese, S. (2013). *Atlas.ti 7 user guide and reference*. Berlin, Germany: ATLAS.ti Scientific Software Development GmbH.
Fripp, G. (2016). Cluster analysis for marketing. Retrieved from http://www.clusteranalysis4marketing.com/
Fulton, K., & Britton, T. (2011). STEM Teachers in Professional Learning Communities: From Good Teachers to Great Teaching. Washington, DC, USA.
Furio, C., Azcona, R., & Guisasola, J. (2002). The learning and teaching of the concepts 'amount of substance'and 'mole': A review of the literature. *Chemistry Education Research and Practice, 3*(3), 277-292.
Furio, C., Azcona, R., Guisasola, J., & Ratcliffe, M. (2000). Difficulties in teaching the concepts of'amount of substance'and'mole'. *International Journal of Science Education, 22*(12), 1285-1304.
Gabel, D. L. (1999). Improving teaching and learning through Chemistry education research: A look to the future. *Journal of Chemical Education, 76*(4), 548 - 554.
Gabel, D. L., & Sherwood, R. D. (1980). Effect of using analogies on Chemistry achievement according to Piagetian level. *Science Education, 64*(5), 709-716.
Gage, N. L. (1984). What do we know about teaching effectiveness? *The Phi Delta Kappan, 66*(2), 87-93.
Ganyaupfu, E. M. (2013). Teaching methods and students' academic performance. *International Journal of Humanities and Social Science Invention, 2*(9), 29-35.
Garrett, R., & Roberts, I. (1982). Demonstration versus small group practical work in science education. A critical review of studies since 1900. *Studies in Science Education, 9*, 109 - 146. doi: 10.1080/03057268208559898
Garritz, A. (2015). PCK for dummies. Part 2: Personal vs Canonical PCK. *Educación Química, 26*(2), 77-80.
Gauchon, L., & Méheut, M. (2007). Learning about stoichiometry: from students' preconceptions to the concept of limiting reactant. *Chemistry Education Research and Practice, 8*(4), 362-375.
Geddis, A. N., Onslow, B., Beynon, C., & Oesch, J. (1993). Transforming content knowledge: Learning to teach about isotopes. *Science Education, 77*(6), 575-591. doi: 10.1002/sce.3730770603
Geddis, A. N., & Wood, E. (1997). Transforming subject matter and managing dilemmas: A case study in teacher education. *Teacher & Teacher Education, 13*(6), 611-626.

Georgiadou, A., & Tsaparlis, G. (2000). Chemistry teaching in lower secondary school with methods based on: A) psychological theories; B) the macro, representational, and submicro levels of Chemistry. *Chemistry Education Research and Practice, 1*(2), 217-226.

Gess-Newsome, J. (1999a). Pedagogical content knowledge: An introduction and orientation. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining Pedagogical content Knowledge: The Construct and its Implications for Science Education* (pp. 3-17). Dordrecht, the The Netherlands Springer/Kluwer Academic Publishers.

Gess-Newsome, J. (1999b). Secondary teachers' knowledge and beliefs about subject matter and their impact on instruction. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The Construct and its Implications for Science Education* (pp. 51-94). Dordrecht, the The Netherlands Springer/Kluwer Academic Publishers.

Gess-Newsome, J. (2015). A model of teacher professional knowledge and skill including PCK: Results of the thinking from the PCK summit. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-Examining Pedagogical Content Knowledge in Science Education* (pp. 28 - 42). Abington, UK: Routledge

Gilbert, J. K., Boulter, C., & Rutherford, M. (1998a). Models in explanations, Part 1: Horses for courses? *International Journal of Science Education, 20*(1), 83-97.

Gilbert, J. K., Boulter, C., & Rutherford, M. (1998b). Models in explanations, Part 2: Whose voice? Whose ears? *International Journal of Science Education, 20*(2), 187-203.

Gilbert, J. K., & Osborne, R. (1980). The use of models in science and science teaching. *European Journal of Science Education, 2*(1), 3-13.

Gilbert, J. K., & Treagust, D. F. (2009). Towards a coherent model for macro, submicro and symbolic representations in chemical education. In J. K. Gilbert & D. Treagust (Eds.), *Multiple representations in chemical education* (pp. 333-350). Dordrecht, Netherlands: Springer.

Gill, P., & Burnard, P. (2008). The student-supervisor relationship in the PhD/Doctoral process. *British Journal of Nursing, 17*(10), 668-672.

Gillespie, R. J., Humphreys, D. A., Baird, D. A., & Robinson, E. A. (1986). *Chemistry*. Boston, Massachusetts: Allyn and Bacon, Inc.

Glaser, B. G. (1965). The constant comparative method of qualitative analysis. *Social problems, 12*(4), 436-445.

Godino, J. D., Batanero, C., Roa, R., & Wilhelmi, M. R. (2008). Assessing and developing pedagogical content and statistical knowledge of primary school teachers through project work. In C. Batanero, G. Burrill, C. Reading, & A. Rossman (Eds.), Joint ICMI/IASE Study: Teaching Statistics in School Mathematics. Challenges for Teacher & Teacher Education. Proceedings of the ICMI study and 2008 LASE Round Table Conference (Vol. 18). Monterrey, Mexico: International Commission on Mathematical Instruction. Retrieved from http://www.mathunion.org/icmi/digital-library/icmi-study-conferences/icmi-study-18-conference/.

Gomez-Zwiep, S. (2008). Elementary teachers' understanding of students' science misconceptions: Implications for practice and teacher education. *Journal of Science Teacher Education, 19*(5), 437-454.

GraphPad Software. (2014). QuickCalcs: t-test calculator. Retrieved from http://www.graphpad.com/quickcalcs/ttest1.cfm

Greeno, J. G. (1997). Response: On claims that answer the wrong questions. *Educational Researcher, 26*(1), 5-17.

Grossman, P. L. (1990). *The making of a teacher: Teacher knowledge and teacher education*. New York, New York, USA: Teachers College Press.

Grossman, P. L. (2011). Framework for teaching practice: A brief history of an idea. *Teachers College Record, 113*(12), 2836-2843.

Grossman, P. L., Hammerness, K., & McDonald, M. (2009). Redefining teaching, re-imagining teacher education. *Teachers and teaching, 15*(2), 273-289. doi: 10.1080/13540600902875340

Grossman, P. L., Wineburg, S., & Woolworth, S. (2000). What Makes Teacher Community Different from a Gathering of Teachers? An Occasional Paper. Washington DC, USA: Center for the Study of Teaching and Policy.

Gudmundsdottir, S. (1990). Values in pedagogical content knowledge. *Journal of Teacher Education, 41*(3), 44-52.
Gudmundsdottir, S., & Shulman, L. (1987). Pedagogical content knowledge in social studies. *Scandinavian Journal of Educational Research, 31*(2), 59-70. doi: 10.1080/0031383870310201
Guetzkow, H. (1950). Unitizing and categorizing problems in coding qualitative data. *Journal of Clinical Psychology, 6*(1), 47-58.
Gulacar, O., Overton, T. L., & Bowman, C. R. (2013). A closer look at the relationships between college students' cognitive abilities and problem solving in stoichiometry. *Eurasia Journal of Mathematics, Science & Technology Education, 5*(2), 144-163.
Gulacar, O., Overton, T. L., Bowmanc, C. R., & Fyneweverd, H. (2013). A novel code system for revealing sources of students' difficulties with stoichiometry. *Chemistry Education Research and Practice, 14*, 507-514.
Handley, K., Sturdy, A., Fincham, R., & Clark, T. (2006). Within and beyond communities of practice: Making sense of learning through participation, identity and practice. *Journal of Management Studies, 43*(3), 641-653. doi: 10.1111/j.1467-6486.2006.00605.x
Hargreaves, A., & Fullan, M. (2012). *Professional capital: Transforming teaching in every school*. Abingdon, Oxon, England: Routledge, Taylor & Francis Group.
Harlin, E.-M. (2014). Watching oneself teach – long-term effects of teachers' reflections on their video-recorded teaching. *Technology, Pedagogy and Education, 23*(4), 507-521. doi: 10.1080/1475939X.2013.822413
Hashweh, M. Z. (1987). Effects of subject-matter knowledge in the teaching of Biology and Physics. *Teacher & Teacher Education, 3*(2), 109-120.
Hashweh, M. Z. (2005). Teacher pedagogical constructions: a reconfiguration of pedagogical content knowledge. *Teachers and teaching, 11*(3), 273-292.
Hassan, G. (2008). Attitudes toward science among Australian tertiary and secondary school students. *Research in Science & Technological Education, 26*(2), 129-147. doi: 10.1080/02635140802034762
Hassard, J. (2005). *The art of science teaching: Inquiry and innovation in middle school and high school*. New York, New York, USA: Oxford University Press, Inc.
Henning, E., Van Rensburg, W., & Smit, B. (2004). *Finding your way in qualitative research*. Pretoria, Gauteng, South Africa: Van Schaik Publishers.
Henze, I., Van Driel, J. H., & Verloop, N. (2008). Development of experienced science teachers' pedagogical content knowledge of models of the solar system and the universe. *International Journal of Science Education, 30*(10), 1321-1342. doi: 10.1080/09500690802187017
Herrmann-Abell, C. F., Flanagan, J. C., & Roseman, J. E. (2013). *Developing and evaluating an eighth grade curriculum unit that links foundational Chemistry to biological growth: Using student measures to evaluate the promise of the intervention*. Paper presented at the National Association for Research in Science Teaching Annual International Conference, Rio Grande, Puerto Rico.
Hewson, P. W. (1981). A conceptual change approach to learning science. *European Journal of Science Education, 3*(4), 383-396.
Hill, J. W., Petrucci, R. H., McCreary, T. W., & Perry, S. S. (2005). *General Chemistry* (4th ed.). Upper Saddle River, New Jersey, USA: Pearson/Prentice-Hall Inc. .
Hoadley, C. (2012). What is a community of practice and how can we support it? In D. H. Jonassen & S. Land (Eds.), *Theoretical foundations of learning environments* (2nd ed., pp. 286-300). New York, New York, USA: Routledge, Taylor & Francis Group.
Hopkins, D., & Stern, D. (1996). Quality teachers, quality schools: International perspectives and policy implications. *Teaching & Teacher Education, 12*(5), 501-517. doi: http://dx.doi.org/10.1016/0742-051X(95)00055-O
Hord, S. M. (1997). Professional learning communities: Communities of continuous inquiry and improvement. Austin, Texas, USA.
Hu, J.-J. (2014). A critical review of Pedagogical Content Knowledge'components: nature, principle and trend. *International Journal of Education and Research, 2*(4), 411-424.

Huddle, P., & Pillay, A. (1996). An in-depth study of misconceptions in stoichiometry and chemical equilibrium at a South African university. *Journal of research in science teaching, 33*(1), 65-77.
Hunter, M., & Russell, D. (1976). Planning for effective instruction: Lesson design. *Instructor*, 23-41.
Jackson, D. F., & Temperley, J. (2007). From professional learning community to networked learning community. In L. Stoll & K. Seashore Louis (Eds.), *Professional Learning Communities: Divergence, Depth & Dilemmas* (pp. 45-62). Berkshire, England: Open University Press, McGraw-Hill Education.
Jaworski, B. (2008). Building and sustaining inquiry communities in mathematics teaching development: Teachers and didacticians in collaboration. In K. Krainer & T. Wood (Eds.), *Participants in Mathematics Teacher Education: Individuals, Teams, Communities and Networks* (pp. 309-330). Rotterdam, the Netherlands: Sense Publishers.
John, P. D. (2006). Lesson planning and the student teacher: re-thinking the dominant model. *Journal of Curriculum Studies, 38*(4), 483-498.
Johnson, R. B., Onwuegbuzie, A. J., & Turner, L. A. (2007). Toward a definition of mixed methods research. *Journal of Mixed Methods Research, 1*(2), 112-133.
Johnstone, A. H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning, 7*(2), 75-83.
Johnstone, A. H. (2000). Teaching of Chemistry-logical or psychological? *Chemistry Education Research and Practice, 1*(1), 9-15.
Kagan, D. M. (1990). Ways of evaluating teacher cognition: Inferences concerning the Goldilocks Principle. *Review of Educational Research, 60*(3), 419-469. doi: 10.2307/1170760
Kalra, M. B., & Baveja, B. (2012). Teacher thinking about knowledge, learning and learners: A metaphor analysis. *Procedia - Social and Behavioral Sciences, 55*, 317-326. doi: http://dx.doi.org/10.1016/j.sbspro.2012.09.509
Kane, M. (2011). The errors of our ways. *Journal of Educational Measurement, 48*(1), 12-30.
Karamustafaoğlu, O. (2007). Evaluation of novice Physics teachers' teaching skills. In S. A. Cetin & I. Hikmet (Eds.), *Proceedings of the Sixth International Conference of the Balkan Physical Union* (Vol. 899, pp. 501-502). Istanbul, Turkey: American Institute of Physics Publishing.
Kelly, A. E. (2003). Research as design. *Educational Researcher, 32*(1), 3-4.
Kind, V. (2009a). A conflict in your head: An exploration of trainee science teachers' subject matter knowledge development and its impact on teacher self-confidence. *International Journal of Science Education, 31*(11), 1529-1562. doi: 10.1080/09500690802226062
Kind, V. (2009b). Pedagogical content knowledge in science education: perspectives and potential for progress. *Studies in Science Education, 45*(2), 169-204.
Kind, V. (2016). Preservice science teachers' science teaching orientations and beliefs about science. *Science Education, 100*(1), 122-152.
Kolb, D. (1978). The mole. *Journal of Chemical Education, 55*(11), 728-732.
Kriek, J., & Grayson, D. (2009). A holistic professional development model for South African physical science teachers. *South African Journal of Education, 29*(2), 185-203.
Krippendorff, K. (2012). *Content analysis: An introduction to its methodology*. Thousand Oaks, California, USA: Sage.
Kullberg, A. (2010). *What is taught and what is learned. Professional insights gained and shared by teachers of mathematics*. Göteborg, Sweden: Acta Universitatis Gothoburgensis, Göteborg Studies in Educational Sciences.
LaFee, S. (2003). Professional Learning Communities. *School Administrator, 60*(5), 6-12.
Lammers, W. J., & Badia, P. (2004). *Fundamentals of Behavioral Research*. Belmont, California, United States: Thomson/Wadsworth.
Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics, 33*, 159-174.
Lange, K., Kleickmann, T., & Moeller, K. (2009). Measuring primary school teachers' pedagogical content knowledge in science education with open-ended and multiple-choice items. In M. F. Tasar & G. Cakmakci (Eds.), *Contemporary Science Education Research: Teaching* (pp. 67-69). Ankara, Turkey: Pegem Akademi.: ESERA.

Lave, J., & Wenger, E. (1998). Communities of practice. Retrieved from: http://valenciacollege.edu/faculty/development/tla/documents/CommunityofPractice.pdf
Lazonby, J., Morris, J., & Waddington, D. (1982). The muddlesome mole. *Education in Chemistry, 19*(4), 109-111.
Lebata, M. C., & Mudau, A. V. (2014). Exploring factors affecting performance in Biology 5090 at selected high schools in Lesotho. *Mediterranean Journal of Social Sciences, 5*(8), 271-278.
Lee, E., & Luft, J. A. (2008). Experienced secondary science teachers' representation of pedagogical content knowledge. *International Journal of Science Education, 30*(10), 1343-1363.
Lee, H.-J. (2005). Developing a professional development program model based on teachers' needs. *Professional Educator, 27*, 39-49.
Lefkowitz, J., & Katz, M. L. (1969). Validity of exit interviews. *Personnel Psychology, 22*(4), 445-455.
Lelliott, A. D. (2008). *Learning about Astronomy: a case study exploring how grade 7 and 8 students experience sites of informal learning in South Africa.* (Doctoral dissertation), University of the Witwatersrand, Johannesburg, South Africa. Retrieved from http://hdl.handle.net/10539/4480
Lewis, C. (2000). *Lesson study: The core of Japanese professional development*. Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans, Louisiana.
Lewis, C. (2004). Does lesson study have a future in the United States? *Journal of Social Science Education, 3*(1), 115 - 137.
Lewis, C., Perry, R., Hurd, J., & O Connell, M. P. (2006). Lesson study comes of age in North America. *The Phi Delta Kappan, 88*(4), 273.
Linacre, J. M. (1998). Do correlations prove scores linear. *Rasch Measurement Transactions, 12*(1), 605-606.
Linacre, J. M. (2002). Immediate raw score to logit conversions. *Rasch Measurement Transactions, 16*(2).
Linacre, J. M. (2012). *A user's guide to winsteps® ministeps (Version 3.74.0)* Retrieved from http://www.winsteps.com
Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Thousand Oaks, California, USA: Sage.
Linder, C. J. (1993). A challenge to conceptual change. *Science Education, 77*(3), 293-300.
Ling, L. M. (2012). *Variation theory and the improvement of teaching and learning*. Göteborg, Sweden: Acta Universitatis Gothoburgensis.
Livingston, C., & Borko, H. (1989). Expert-novice differences in teaching: A cognitive analysis and implications for teacher education. *Journal of Teacher Education, 40*(4), 36-42. doi: 10.1177/002248718904000407
Lo, M. L., & Chik, P. P. M. (2016). Two horizons of fusion. *Scandinavian Journal of Educational Research, 60*(3), 296-308. doi: 10.1080/00313831.2015.1119730
Lodico, M. G., Spaulding, D. T., & Voegtle, K. H. (2010). *Methods in educational research: From theory to practice* (2nd ed.). San Francisco, California, USA: Jossey-Bass Publishers.
Loughran, J. (2009). Is teaching a discipline? Implications for teaching and teacher education. *Teachers and teaching, 15*(2), 189-203. doi: 10.1080/13540600902875290
Loughran, J. (2010). *What expert teachers do: Enhancing professional knowledge for classroom practice*. Abingdon, Oxon, UK: Routledge, Taylor & Francis Group.
Loughran, J. (2012). *What expert teachers do: Enhancing professional knowledge for classroom practice*. New York, New York: Routledge.
Loughran, J. (2014). Recognizing and valuing teachers' professional knowledge of practice In H. Venkat, M. Rollnick, J. Loughran, & M. Askew (Eds.), *Exploring Mathematics and Science Teachers Knowledge: Windows into Teacher Thinking* (pp. 195 - 203). Abingdon, London, United Kingdom: Routledge, Taylor & Francis Group.
Loughran, J., Berry, A., & Mulhall, P. (2012). *Understanding and developing science teachers' pedagogical content knowledge* (2nd ed.). Rotterdam, The Netherlands: Sense Publishers.

Loughran, J., Gunstone, R., Berry, A., Milroy, P., & Mulhall, P. (2000a). *Documenting science teachers' pedagogical content knowledge through PaP-eRs.* Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans, Louisiana.

Loughran, J., Gunstone, R., Berry, A., Milroy, P., & Mulhall, P. (2000b). *Science cases in action: Developing an understanding of science teachers' pedagogical content knowledge*. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, New Orleans, Louisiana.

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

Loughran, J., Mulhall, P., & Berry, A. (2008). Exploring pedagogical content knowledge in science teacher education. *International Journal of Science Education, 30*(10), 1301-1320.

Loughran, J., & Russell, T. (2009). Teaching as a discipline. *Teachers and teaching, 15*(2), 183-187. doi: 10.1080/13540600902875282

Luft, J. A. (2009). Preservice teachers' instructional beliefs and examination of consistency between beliefs and practices. *International Journal of Science and Mathematics Education, 7*, 1173-1199.

Luft, J. A., & Roehrig, G. H. (2007). Capturing science teachers' epistemological beliefs: The development of the teacher beliefs interview. *Electronic Journal of Science Education, 11*(2).

Lumpe, A., Vaughn, A., Henrikson, R., & Bishop, D. (2014). Teacher professional development and self-efficacy beliefs. In R. Evans, J. Luft, C. M. Czerniak, & C. Pea (Eds.), *The Role of Science Teachers' Beliefs in International Classrooms* (pp. 49-63). Rotterdam, Netherlands: Sense Publishers.

Lunenberg, M., & Korthagen, F. (2009). Experience, theory, and practical wisdom in teaching and teacher education. *Teachers and teaching, 15*(2), 225-240. doi: 10.1080/13540600902875316

Mackay, J., & Hobden, P. (2012). Using circuit and wiring diagrams to identify students' preconceived ideas about basic electric circuits. *African Journal of Research in Mathematics, Science and Technology Education, 16*(2), 131-144. doi: 10.1080/10288457.2012.10740735

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining Pedagogical Content Knowledge: The Construct and its Implications for Science Education* (pp. 95-132). Dordrecht, the The Netherlands Springer/Kluwer Academic Publishers.

Malcolm, S. A. (2015). *The design and validation of an instrument to measure topic-specific pedagogical content knowledge in stoichiometry of Physical Sciences teachers.* (Unpublished Master of Science research report), University of the Witwatersrand, Johannesburg, South Africa. Retrieved from https://www.researchgate.net/publication/283672432

Marton, F., & Pang, M. F. (2006). On some necessary conditions of learning. *The journal of the learning sciences, 15*(2), 193-220.

Marton, F., & Trigwell, K. (2000). Variatio est mater studiorum. *Higher Education Research and Development, 19*(3), 381-395.

Masterton, W. L., Slowinski, E. J., & Stanitski, C. L. (1985). *Chemical principles* (6th ed.). Philadelphia, Pennsylvania: Saunders College Publishing.

Mathewson Mitchell, D., & Reid, J.-A. (2017). (Re)turning to practice in teacher education: embodied knowledge in learning to teach. *Teachers and teaching, 23*(1), 42-58. doi: 10.1080/13540602.2016.1203775

Mavhunga, E. (2012). *Explicit inclusion of topic specific knowledge for teaching and the development of PCK in pre-service science teachers.* (Doctoral dissertation), University of the Witwatersrand, Johannesburg, South Africa. Retrieved from http://wiredspace.wits.ac.za/handle/10539/15877

Mavhunga, E. (2014). Improving PCK and CK in pre-service Chemistry teachers. In H. Venkat, M. Rollnick, J. Loughran, & M. Askew (Eds.), *Exploring Mathematics and Science Teachers Knowledge: Windows into Teacher Thinking.* (pp. 31 - 48). Abingdon, London, United Kingdom: Routledge, Taylor & Francis Group.

Mavhunga, E. (2015). *The nature of interactions of the components of topic specific pedagogical content knowledge*. Paper presented at the Southern African Association for Research in Mathematics, Science and Technology Education, Maputo, Mozambique.
Mavhunga, E. (2016). Transfer of the pedagogical transformation competence across chemistry topics. *Chemistry Education Research and Practice, 17*(4), 1081-1097. doi: 10.1039/C6RP00095A
Mavhunga, E., & Rollnick, M. (2013). Improving pck of chemical equilibrium in pre-service teachers. *African Journal of Research in Mathematics, Science & Technology Education, 17*(1-2), 113–125.
Mavhunga, E., & van der Merwe, D. (2017). *Revealing the complexity of pre-service teachers' TSPCK: From reasoning to practice*. Paper presented at the 12th Conference of the European Science Education Research Association, Dublin, Republic of Ireland.
McAlpine, L., & Weston, C. (2000). Reflection: Issues related to improving professors' teaching and students' learning. *Instructional Science, 28*, 363–385.
McKim, C. A. (2015). The value of mixed methods research: A mixed methods study. *Journal of Mixed Methods Research*. doi: 10.1177/1558689815607096
McLaughlin, M. W., & Talbert, J. E. (2007). Building professional learning communities in high schools: Challenges and promising practices. In L. Stoll & K. Seashore Louis (Eds.), *Professional Learning Communities: Divergence, Depth & Dilemmas* (pp. 151-165). Berkshire, England: Open University Press, McGraw-Hill Education.
McMillan, J. H., & Schumacher, S. (2010). *Research in education: Research-based inquiry* (7th ed.). Upper Saddle River, New Jersey: Pearson Education, Inc.
Merriam, S. B. (1998). *Qualitative research and case studies application in education*. San Francisco, California, USA: Johnny-Bass.
Miheso, J., & Mavhunga, E. (2018). *The development and validation of a rubric for assessing teachers' TSPCK classroom practices*. Paper presented at the Southern African Association for Research in Mathematics, Science and Technology Education,, Gabarone, Botswana.
Milton, M., J. T., & Mills, I. M. (2009). Amount of substance and the proposed redefinition of the mole. *Metrologia, 46*(3), 332 - 338.
Mitchell, A. (1997). Teacher identity: A key to increased collaboration. *Action in Teacher Education, 19*(3), 1-14. doi: 10.1080/01626620.1997.10462875
Mitchell, C., & Sackney, L. (2007). Extending the learning community: A broader perspective embedded in policy. In L. Stoll & K. Seashore Louis (Eds.), *Professional Learning Communities: Divergence, Depth & Dilemmas* (pp. 30-44). Berkshire, England: Open University Press, McGraw-Hill Education.
Mitchell, I., Keast, S., Panizzon, D., & Mitchell, J. (2017). Using 'big ideas' to enhance teaching and student learning. *Teachers and teaching, 23*(5), 596-610.
Mnguni, L. (2013). The curriculum ideology of the South African secondary school Biology. *South African Journal of Education, 33*(2), 1-11.
Mooi, E., & Sarstedt, M. (2011). Cluster analysis *A Concise Guide to Market Research: The Process, Data and Methods using IBM SPSS* (pp. 237-284). Berlin, Germany: Springer-Verlag.
Moran-Ellis, J., Alexander, V. D., Cronin, A., Dickinson, M., Fielding, J., Sleney, J., & Thomas, H. (2006). Triangulation and integration: processes, claims and implications. *Qualitative Research, 6*(1), 45-59. doi: 10.1177/1468794106058870
Morrison, A. D., & Luttenegger, K. C. (2015). Measuring pedagogical content knowledge using multiple points of data. *The qualitative report, 20*(6), 804-816.
Mukaka, M. M. (2012). A guide to appropriate use of correlation coefficient in medical research. *Malawi Medical Journal, 24*(3), 69-71.
Mulhall, P., Berry, A., & Loughran, J. (2003). Frameworks for representing science teachers' pedagogical content knowledge. *Asia-Pacific Forum on Science Learning and Teaching, 4*(2). Retrieved from: https://www.ied.edu.hk/apfslt/v4_issue2/index.htm
Mullens, J. E., Murnane, R. J., & Willett, J. B. (1996). The contribution of training and subject matter knowledge to teaching effectiveness: A multilevel analysis of longitudinal evidence from belize. *Comparative Education Review, 40*(2), 139-157.

Munby, H. (1986). Metaphor in the thinking of teachers: An exploratory study. *Journal of Curriculum Studies, 18*(2), 197-209. doi: 10.1080/0022027860180209
Munby, H., Russell, T., & Martin, A. K. (2001). Teachers' knowledge and how it develops. In V. Richardson (Ed.), *Handbook of Research on Teaching* (4th ed., pp. 887-904). Washington, DC, USA: American Educational Research Association.
Ndlovu, M. (2014). *The design of an instrument to measure physical science teachers' topic specific pedagogical content knowledge in electrochemistry.* (Masters' Research Report), University of the Witwatersrand, Johannesburg, South Africa. Retrieved from http://hdl.handle.net/10539/14920
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), 3-11. doi: 10.1007/s10698-013-9185-1
Nguyen, N. T., McFadden, A., Tangen, D. J., & Beutel, D. A. (2013). *Video-stimulated recall interviews in qualitative research*. Paper presented at the Joint Australian Association for Research in Education, Adelaide, Australia.
Nie, Y., Lau, S., & Liau, A. K. (2010). The teacher efficacy scale: A reliability and validity study. *The Asia-Pacific Education Researcher, 21*(2), 414-421.
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. doi: 10.1080/09500690802186993
Nilsson, P. (2014). When teaching makes a difference: Developing science teachers' pedagogical content knowledge through learning study. *International Journal of Science Education, 36*(11), 1794-1814. doi: 10.1080/09500693.2013.879621
Nilsson, P., & Vikström, A. (2015). Making PCK explicit: Capturing science teachers' pedagogical content knowledge (PCK) in the science classroom. *International Journal of Science Education*, 1-22. doi: 10.1080/09500693.2015.1106614
Norwood, J. (2007). Professional learning communities to increase student achievement. *Essays in Education, 20*. Retrieved from: http://www.usca.edu/essays/vol202007/norwoodrev.pdf
Novick, S., & Menis, J. (1976). A study of student perceptions of the mole concept. *Journal of Chemical Education, 53*(11), 720 - 722.
Okanlawon, A. E. (2010). Teaching Reaction Stoichiometry: Exploring and Acknowledging Nigerian Chemistry Teachers Pedagogical Content Knowledge. *Cypriot Journal of Educational Sciences, 5*(2), 107-129.
Olsson, K. A., Balgopal, M. M., & Levinger, N. E. (2015). How did we get here? Teaching chemistry with a historical perspective. *Journal of Chemical Education, 92*(11), 1773-1776.
Ono, Y., & Ferreira, J. (2010). A case study of continuing teacher professional development through lesson study in South Africa. *South African Journal of Education, 30*(1), 59-74.
Onwuegbuzie, A. J., & Johnson, R. B. (2006). The validity issue in mixed research. *Research in the Schools, 13*(1), 48-63.
Opie, C. (2004). *Doing educational research*. London, United Kingdom: SAGE Publications Ltd.
Ortlipp, M. (2008). Keeping and using reflective journals in the qualitative research process. *The qualitative report, 13*(4), 695-705.
Ozden, M. (2008). The effect of content knowledge on pedagogical content knowledge: The case of teaching phases of matters. *Educational sciences: theory and practice, 8*(2), 633-645.
Packer, J. (1988). Difficulties with stoichiometry. *Education in Chemistry, 25*(3), 92-95.
Padilla, K., & Garritz, A. (2011). *The pedagogical content knowledge of university Chemistry professors teaching stoichiometry.* Paper presented at the Proceedings of the NATIONAL ASSOCIATION FOR RESEARCH IN SCIENCE TEACHING 2011 Conference, Orlando, Florida.
Padilla, K., Ponce-de-León, A. M., Rembado, F. M., & Garritz, A. (2008). Undergraduate professors' pedagogical content knowledge: The case of 'amount of substance'. *International Journal of Science Education, 30*(10), 1389-1404. doi: 10.1080/09500690802187033
Pang, M. F., & Ki, W. W. (2016). Revisiting the idea of "Critical Aspects". *Scandinavian Journal of Educational Research, 60*(3), 323-336. doi: 10.1080/00313831.2015.1119724

Pang, M. F., & Ling, L. M. (2012). Learning study: helping teachers to use theory, develop professionally, and produce new knowledge to be shared. *Instructional Science, 40*(3), 589-606. doi: 10.1007/s11251-011-9191-4

Pang, M. F., & Marton, F. (2003). Beyond``lesson study'': Comparing two ways of facilitating the grasp of some economic concepts. *Instructional Science, 31*(3), 175-194.

Pang, M. F., & Marton, F. (2005). Learning Theory as teaching resource: Enhancing students' understanding of Economic concepts. *Instructional Science, 33*(2), 159-191. doi: 10.1007/s11251-005-2811-0

Pang, M. F., & Marton, F. (2007). The paradox of pedagogy. The relative contribution of teachers and learners to learning. *Iskolakultura, 1*(1), 1-29. Retrieved from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.547.7584&rep=rep1&type=pdf

Park, S., & Chen, Y.-C. (2012). Mapping out the integration of the components of pedagogical content knowledge (PCK): Examples from high school Biology classrooms. *Journal of research in science teaching, 49*(7), 922-941.

Park, S., Jang, J.-Y., Chen, Y.-C., & Jung, J. (2011). Is pedagogical content knowledge (PCK) necessary for reformed science teaching?: Evidence from an empirical study. *Research in Science Education, 41*(2), 245-260.

Park, S., Jang, J.-Y., Chen, Y.-L., & Jung, J. (2008). *Developing measures of teachers' pedagogical content knowledge for teaching school biology*. Paper presented at the The International Conference o the Association for Science Teacher Education, St. Louis, Michigan, USA.

Park, S., & Oliver, J. S. (2008). Revisiting the conceptualisation of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. *Research in Science Education, 38*(3), 261-284.

Pekdağ, B., & Azizoğlu, N. (2013). Semantic mistakes and didactic difficulties in teaching the "amount of substance" concept: a useful model. *Chemistry Education Research and Practice, 14*(1), 117-129.

Pentecost, T. C., & Barbera, J. (2013). Measuring learning gains in chemical education: A comparison of two methods. *Journal of Chemical Education, 90*(7), 839-845. doi: 10.1021/ed400018v

Perry, R. R., & Lewis, C. C. (2009). What is successful adaptation of lesson study in the US? *Journal of Educational Change, 10*(4), 365-391.

Pesudovs, K., Burr, J. M., Harley, C., & Elliott, D. B. (2007). The development, assessment, and selection of questionnaires. *Optometry & Vision Science, 84*(8), 663-674.

Piepgrass, K. W. (1998). Audience-appropriate analogies: Collision theory. *Journal of Chemical Education, 75*(6), 724 -

Pitjeng, R. J. (2014). *Investigating the effect of an intervention on novice science teachers topic specific pedagogical content knowledge.* (Doctoral dissertation), University of the Witwatersrand, Johannesburg, South Africa Retrieved from http://mobile.wiredspace.wits.ac.za/handle/10539/17803

Polkinghorne, D. E. (1995). Narrative configuration in qualitative analysis. *International Journal of Qualitative Studies in Education, 8*(1), 5-23. doi: 10.1080/0951839950080103

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211-227.

Potgieter, M., Rogan, J. M., & Howie, S. (2005). Chemical concepts inventory of Grade 12 learners and UP foundation year students. *African Journal of Research in Mathematics, Science & Technology Education, 9*(2), 121-134.

Prieto, L., Alonso, J., & Lamarca, R. (2003). Classical test theory versus Rasch analysis for quality of life questionnaire reduction. *Health and quality of life outcomes, 1*(1). Retrieved from: https://hqlo.biomedcentral.com/articles/10.1186/1477-7525-1-27

Punj, G., & Stewart, D. W. (1983). Cluster analysis in marketing research: Review and suggestions for application. *Journal of marketing research, 20*(2), 134-148.

Ramnarain, U., & Fortus, D. (2013). South African physical sciences teachers' perceptions of new content in a revised curriculum. *South African journal of education, 33*(1), 1-15.

Randolph, J. J. (2005). *Free-marginal multirater kappa (multirater k [free]): An alternative to Fleiss' fixed-marginal multirater kappa*. Paper presented at the Joensuu Learning and Instruction Symposium, Joensuu, Finland.

Reichstetter, R. (2006) Defining a professional learning community. *Vol. 06.05. E & R Research Alert*. Raleigh, North Carolina, USA: Wake County Public School System.

Roehrig, G. H., & Kruse, R. A. (2005). The role of teachers' beliefs and knowledge in the adoption of a reform-based curriculum. *School Science and Mathematics, 105*(8), 412-422.

Rohaan, E. J., Taconis, R., & Jochems, W. M. G. (2009). Measuring teachers' pedagogical content knowledge in primary technology education. *Research in Science & Technological Education, 27*(3), 327-338.

Rohaan, E. J., Taconis, R., & Jochems, W. M. G. (2011). Exploring the underlying components of primary school teachers' pedagogical content knowledge for technology education. *Eurasia Journal of Mathematics, Science & Technology Education, 7*(4), 263-274.

Rollnick, M. (2018). *Analysing science teachers' pedagogical content knowledge - the second PCK summit: Perspectives from participants and spectators* Paper presented at the 26th Annual Conference of the Southern African Association for Research in Mathematics, Science and Technology Education., Gaborone, Botswana.

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

Rollnick, M., & Mavhunga, E. (2014). PCK of teaching electrochemistry in Chemistry teachers: A case in Johannesburg, Gauteng Province, South Africa. *Educación Química, 25*(3), 354-362.

Rollnick, M., & Mavhunga, E. (2015). The PCK summit and its effect on work in South Africa. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-Examining Pedagogical Content Knowledge in Science Education* (pp. 135 - 146). Abington, UK: Routledge

Rollnick, M., & Mavhunga, E. (2017). [Revised PCK Model from second PCK Summit in the Nehterlands].

Rosenshine, B., & Stevens, R. (1986). Teaching functions. In M. Wittrock (Ed.), *Handbook of Research on Teaching* (3rd ed., pp. 376-391). New York, New York, USA.: Macmillan Publishing Company.

Rowan, B., Schilling, S. G., Ball, D. L., Miller, R., Atkins-Burnett, S., Camburn, E., Harrison, D.*, et al.* (2001). Measuring teachers' pedagogical content knowledge in surveys: An exploratory study. Philadelphia, Pennsylvania.

Rusznyak, L., & Walton, E. (2011). Lesson planning guidelines for student teachers: A scaffold for the development of pedagogical content knowledge. *Education as Change, 15*(2), 271-285. doi: 10.1080/16823206.2011.619141

Salzberger, T. (2010). Does the Rasch model convert an ordinal scale into an interval scale. *Rasch Measurement Transactions, 24*(2), 1273-1275.

Sarstedt, M., & Mooi, E. (2014). Cluster analysis *A Concise Guide to Market Research* (pp. 273-324). Berlin, Germany: Springer-Verlag.

Sato, M., Akita, K., & Iwakawa, N. (1993). Practical thinking styles of teachers: A comparative study of expert and novice thought processes and its implications for rethinking teacher education in Japan. *Peabody Journal of Education, 68*, 100–110.

Schmidt, H. J. (1994). Stoichiometric problem solving in high school Chemistry. *International Journal of Science Education, 16*(2), 191-200.

Schmidt, H. J. (1997). An alternate path to stoichiometric problem solving. *Research in Science Education, 27*(2), 237-249.

Schmidt, H. J., & Jignéus, C. (2003). Students strategies in solving algorithmic stoichiometry problems. *Chemistry Education Research and Practice, 4*(3), 305-317.

Schneider, R., & Krajcik, J. (2002). Supporting science teacher learning: The role of educative curriculum materials. *Journal of Science Teacher Education, 13*(3), 221-245. doi: 10.1023/A:1016569117024

Shavelson, R. J., Webb, N. M., & Burstein, L. (1986). Measurement of teaching. In M. Wittrock (Ed.), *Handbook of Research on Teaching* (pp. 50-91). New York, New York, USA: Macmillan Publishing Company.

Shulman, L. S. (1986a). Paradigms and research programs in the study of teaching: A contemporary perspective. In M. C. Wittrock (Ed.), *Handbook of Research on Teaching* (3rd ed., pp. 3-36). New York, New York, USA: Macmillan Publishing Company.

Shulman, L. S. (1986b). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1-23.

Shulman, L. S. (1988). A union of insufficiencies: Strategies for teacher assessment in a period of educational reform. *Educational Leadership, 46*(3), 36-41.

Shulman, L. S. (2004a). Research on teaching: A historical and personal perspective. In L. S. Shulman, S. M. Wilson, & P. Hutchings (Eds.), *The wisdom of practice: Essays on teaching, learning, and learning to teach* (pp. 363-381). San Francisco, California, USA: Jossey-Bass, A Wiley Imprint.

Shulman, L. S. (2004b). Teaching alone, learning together: Needed agendas for the new reforms. In L. S. Shulman, S. M. Wilson, & P. Hutchings (Eds.), *The wisdom of practice: Essays on teaching, learning, and learning to teach* (pp. 310-333). San Francisco, California, USA: Jossey-Bass, A Wiley Imprint.

Shulman, L. S. (2004c). The wisdom of practice: Managing complexity in medicine and teaching. In L. S. Shulman, S. M. Wilson, & P. Hutchings (Eds.), *The wisdom of practice: Essays on teaching, learning, and learning to teach* (pp. 251-275). San Francisco, California, USA: Jossey-Bass, A Wiley Imprint.

Shulman, L. S. (2007). Response to comments: Practical wisdom in the service of professional practice. *Educational Researcher, 36*(9), 560-563.

Shulman, L. S. (2015). PCK: Its genesis and exodus. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-Examining Pedagogical Content Knowledge in Science Education* (pp. 3 - 13). Abington, UK: Routledge

Silberberg, M. S. (2006). *Chemistry: The molecular nature of matter and change* (5th ed.). New York, New York: McGraw-Hill Higher Education.

Skoog, D. A., West, D. M., Holler, F. J., & Crouch, S. R. (2004). *Fundamentals of analytical Chemistry*. Belmont, California: Brooks/Cole Thomson Learning, Inc.

Smith, C., Blake, A., Kelly, F., Gray, P., McKie, M., & Mcnally, J. (2011). *'Just give me the answer': developing pedagogical process knowledge (PPK) as part of practitioner theory in the pursuit of inquiry-based science teaching*. Paper presented at the The European Conference on Educational Research 2011.

Smith, M. K. (2003). Communities of practice. *The encyclopedia of informal education*. Retrieved from: www.infed.org/biblio/communities_of_practice.htm.

Spaull, N. (2013). South Africa's education crisis: The quality of education in South Africa 1994-2011. Johannesburg, South Africa: Centre for Development & Enterprise.

Stake, R. (1988). Cast study methods. In R. M. Jager (Ed.), *Complementary Methods in Research for Eeducation* (pp. 251-279). Washington, DC, USA: American Educational Research Association.

Stamovlasis, D., Tsaparlis, G., Kamilatos, C., Papaoikonomou, D., & Zarotiadou, E. (2004). Conceptual understanding versus algorithmic problem solving: A principal component analysis of a national examination. *The Chemical Educator, 9*(6), 398-405.

Stamovlasis, D., Tsaparlis, G., Kamilatos, C., Papaoikonomou, D., & Zarotiadou, E. (2005). Conceptual understanding versus algorithmic problem solving: Further evidence from a national chemistry examination. *Chemistry Education Research and Practice, 6*(2), 104-118.

Stangroom, J. (2017). Wilcoxon signed-rank test calculator. Retrieved from http://www.socscistatistics.com/tests/signedranks/Default2.aspx

Starkey, L., Yates, A., Meyer, L. H., Hall, C., Taylor, M., Stevens, S., & Toia, R. (2009). Professional development design: Embedding educational reform in New Zealand. *Teacher & Teacher Education, 25*(1), 181-189. doi: http://dx.doi.org/10.1016/j.tate.2008.08.007

Staver, J. R., & Lumpe, A. T. (1993). A content analysis of the presentation of the mole concept in Chemistry textbooks. *Journal of research in science teaching, 30*(4), 321-337.

Stender, A., Brückmann, M., & Neumann, K. (2017). Transformation of topic-specific professional knowledge into personal pedagogical content knowledge through lesson planning. *International Journal of Science Education, 39*(12), 1690-1714.

Stewart, J. (2012). Does IRT provide more sensitive measures of latent traits in statistical tests? An empirical examination. *Shiken Research Bulletin, 16*(1), 15-22.

Stewart, R., & Brendefur, J. (2005). Fusing lesson study and authentic achievement. *The Phi Delta Kappan, 86*(9), 681-687.

Steyn, G. (2008). Continuing professional development for teachers in South Africa and social learning systems: conflicting conceptual frameworks of learning. *Koers, 73*(1), 15-31.

Stoffels, N. T. (2004). *Why teachers do what they do: Exploring teacher decision-making frames in the context of curriculum change in South Africa*. Paper presented at the Australian Association for Research in Education Annual Conference, Melbourne, Victoria, Australia.

Stoffels, N. T. (2005). " There is a worksheet to be followed": a case study of a science teacher's use of learning support texts for practical work. *African Journal of Research in Mathematics, Science & Technology Education, 9*(2), 147-157.

Stoll, L., Bolam, R., McMahon, A., Wallace, M., & Thomas, S. (2006). Professional learning communities: A review of the literature. *Journal of Educational Change, 7*(4), 221-258.

Stoll, L., & Seashore Louis, K. (2007). Professional learning communities: Elaborating new approaches. In L. Stoll & K. Seashore Louis (Eds.), *Professional Learning Communities: Divergence, Depth & Dilemmas* (pp. 1-13). Berkshire, England: Open University Press, McGraw-Hill Education.

Strike, K. A., & Posner, G. J. (1982). Conceptual change and science teaching. *European Journal of Science Education, 4*(3), 231-240.

Strömdahl, H. R. (1996). *On mole and amount of substance. A study of the dynamics of concept formation and concept attainment*. Göteborg: Sweden: Acta Universitatis Gothoburgensis, Göteborg Studies in Educational Sciences.

Strömdahl, H. R. (2008). Critical features of word meaning as an educational tool in learning and teaching natural sciences. In L. Taxén (Ed.), *Proceedings of the 13th International Conference on Thinking: June 17-21, 2007* (pp. 181-185). Norrköping, Sweden: Linköping University Electronic Press.

Strömdahl, H. R., Tullberg, A., & Lybeck, L. (1994). The qualitatively different conceptions of 1 mol. *International Journal of Science Education, 16*(1), 17-26.

Suh, J. K., & Park, S. (2017). Exploring the relationship between pedagogical content knowledge (PCK) and sustainability of an innovative science teaching approach. *Teaching and teacher education, 64*, 246-259.

Symington, D., & Osborne, R. (1985). Toward professional development in science education for the primary school teacher. *European Journal of Science Education, 7*(1), 19-28.

Taber, K. S. (2009). Learning at the symbolic level. In J. K. Gilbert & D. Treagust (Eds.), *Multiple representations in chemical education* (pp. 75-105). Dordrecht, Netherlands: Springer.

Talanquer, V. (2013a). Chemistry education: ten facets to shape us. *Journal of Chemical Education, 90*(7), 832-838.

Talanquer, V. (2013b). School Chemistry: The need for transgression. *Science & Education, 22*(7), 1757-1773.

Taole, M. J. (2013). Teachers' conceptions of the curriculum review process. *International Journal of Education in Science, 5*(1), 39-46.

Tashakkori, A., & Creswell, J. W. (2007). Editorial: The new era of mixed methods. *Journal of Mixed Methods Research, 1*(3), 3-7. doi: 10.1177/2345678906293042

Taylor, B. N., & Thompson, A. (Eds.). (2008). *The international system of units (SI)* (8th ed.). Gaithersburg, MD: National Institue of Standards and Technology.

Teddlie, C., & Tashakkori, A. (2009). *Foundations of mixed methods research. Integrating quantitative and qualitative approaches in the social and behavioral sciences*. Thousand Oaks, California, USA Sage.

Thomson, M. M., Di Francesca, D., Mcintyre, E., Carrier, S. J., & Zulli Lowe, R. (2013). *Beliefs and knowledge: Exploring relationships between science and mathematics teaching self-efficacy beliefs, pedagogical content knowledge (PCK), and domain knowledge among preservice teachers*. Paper presented at the Annual Meeting of the American Educational Research Association, San Francisco, California, USA.

Toerien, R. (2017). *Mapping the learning trajectories of physical sciences teachers' topic specific knowledge for teaching chemical bonding.* (Doctoral dissertation), University of Cape Town, University of Cape Town, Cape Town, Western Cape, South Africa Retrieved from http://open.uct.ac.za/handle/11427/25508

Toma, J. D. (2000). How getting close to your subjects makes qualitative data better. *Theory into Practice, 39*(3), 177-184. doi: 10.1207/s15430421tip3903_9

Tóth, Z., & Sebestyén, A. (2009). Relationship between students' knowledge structure and problem-solving strategy in stoichiometric problems based on the chemical equation. *Eurasian Journal of Physics and Chemistry Education, 1*(1), 8-20.

Tröger, H., Strübe, M., Sumfleth, E., & Tepner, O. (2014). Professional knowledge of Chemistry teachers video analysis of Chemistry lessons. In C. P. Constantinou, N. Papadouris, & A. Hadjigeorgiou (Eds.), *E-Book Proceedings of the ESERA 2013 Conference: Science Education Research For Evidence-based Teaching and Coherence in Learning* (Vol. 3: Science teaching processes (co-eds. A. Tiberghien & E. A Kyza), pp. 537-542). Nicosia, Cyprus European Science Education Research Association.

Tryfos, P. (1998). Cluster analysis *Methods for Business Analysis and Forecasting: Text and Case*. Ney York, New York: Wiley.

Tsang, W. K. (2004). Teachers' personal practical knowledge and interactive decisions. *Language Teaching Research, 8*(2), 163-198. doi: 10.1191/1362168804lr139oa

Tsaparlis, G. (2009). Learning at the macro level: The role of practical work. In J. K. Gilbert & D. Treagust (Eds.), *Multiple representations in chemical education* (pp. 109-136). Dordrecht, Netherlands: Springer.

Tschannen-Moran, M., & Hoy, A. W. (2001). Teacher efficacy: Capturing an elusive construct. *Teacher & Teacher Education, 17*(7), 783-805.

Tschannen-Moran, M., Hoy, A. W., & Hoy, W. K. (1998). Teacher efficacy: Its meaning and measure. *Review of Educational Research, 68*(2), 202-248.

Tuckman, B. W. (1995). Assessing effective teaching. *Peabody Journal of Education, 70*(2), 127-138. doi: 10.1080/01619569509538827

Tullberg, A., Strömdahl, H. R., & Lybeck, L. (1994). Students' conceptions of 1 mol and educators' conceptions of how they teach 'the mole'. *International Journal of Science Education, 16*(2), 145-156.

van Berkel, B., Pilot, A., & Bulte, A. M. (2009). Micro–macro thinking in chemical education: Why and how to escape. In J. K. Gilbert & D. Treagust (Eds.), *Multiple representations in chemical education* (pp. 31-54). Dordrecht, Netherlands: Springer.

van der Merwe, D. (2018). *Examining pre-service teachers' reflections on their classroom teaching in order to identify Topic Specific Pedagogical Content Knowledge in their practice.* (Masters research report), University of the Witwatersrand, University of the Witwatersrand, Johannesburg, South Africa.

Van Driel, J. H., & Berry, A. (2010). Pedagogical content knowledge. In B. McGraw, P. L. Peterson, & E. Baker (Eds.), *International encyclopedia of education* (3rd ed., pp. 656-651). Oxford, England, U.K.: Elsevier.

Van Driel, J. H., De Jong, O., & Verloop, N. (2002). The development of preservice Chemistry teachers' pedagogical content knowledge. *Science Education, 86*(4), 572-590.

Van Driel, J. H., Verloop, N., & de Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of research in science teaching, 35*(6), 673-695.

Veal, W. R., & MaKinster, J. G. (1999). Pedagogical content knowledge taxonomies. *Electronic Journal of Science Education, 3*(4). Retrieved from: http://ejse.southwestern.edu/article/viewArticle/7615/5382

Veal, W. R., Tippins, D. J., & Bell, J. (1999). The evolution of pedagogical content knowledge in prospective secondary Physics teachers. The Educational Resources Information Center http://files.eric.ed.gov/fulltext/ED443719.pdf

Verhoef, N. C., Coenders, F., Pieters, J. M., van Smaalen, D., & Tall, D. O. (2015). Professional development through lesson study: Teaching the derivative using GeoGebra. *Professional Development in Education, 41*(1), 109-126. doi: 10.1080/19415257.2014.886285

Verloop, N., Van Driel, J. H., & Meijer, P. (2001). Teacher knowledge and the knowledge base of teaching. *International Journal of Educational Research, 35*(5), 441-461.

Vokwana, N. (2013). *Development and validation of instruments to assess content knowledge and topic-specific pedagogical content knowledge of teachers of organic Chemistry.* (Masters' thesis), University of the Cape Town, Cape Town, South Africa. . Retrieved from http://hdl.handle.net/11427/6634

Wagner, J. (1997). The unavoidable intervention of educational research: A framework for reconsidering researcher-practitioner cooperation. *Educational Researcher, 26*(7), 13-22. doi: 10.2307/1177125

Walberg, H. J. (1977). Decision and Perception: New constructs for research on teaching effects. *Cambridge Journal of Education, 7*(1), 33-39. doi: 10.1080/0305764770070105

Wenger, E. (1998a). Communities of practice: Learning as a social system. *Systems thinker, 9*(5), 2-3.

Wenger, E. (1998b). *Communities of practice: Learning, meaning, and identity*. Cambridge, United Kingdom: Cambridge University Press.

Wenger, E. (2000). Communities of practice and social learning systems. *Organization, 7*(2), 225-246. doi: 10.1177/135050840072002

Wenger, E. (2009). Communities of practice: A brief introduction. *Communities*. Retrieved from: http://neillthew.typepad.com/files/communities-of-practice.pdf

Wenger, E. (2010). Communities of practice and social learning systems: the career of a concept. In C. Blackmore (Ed.), *Social Learning Systems and Communities of Practice* (pp. 179-198). London, United Kingdom: Springer-Verlag London Ltd.

Wenger, E. (2011). Communities of practice: A brief introduction. *Scholars' Bank*. Retrieved from University of Oregon Libraries website: https://scholarsbank.uoregon.edu/xmlui/bitstream/handle/1794/11736/A%20brief%20introduction%20to%20CoP.pdf?sequence=1&isAllowed=y

White, H., & Sabarwal, S. (2014). Quasi-experimental design and methods. *Methodological Briefs: Impact Evaluation, 8*. Retrieved from: https://www.unicef-irc.org/publications/pdf/brief_8_quasi-experimental%20design_eng.pdf

Whitfield, R. (1977). A note on research implications of the decision-making model of teaching. *Cambridge Journal of Education, 7*(1), 86-88. doi: 10.1080/0305764770070109

Williams, J., Eames, C., Hume, A., & Lockley, J. (2012). Promoting pedagogical content knowledge development for early career secondary teachers in science and technology using content representations. *Research in Science & Technological Education, 30*(3), 327-343.

Wilson, N. S. (2008). Teachers expanding pedagogical content knowledge: Learning about formative assessment together. *Journal of In-Service Education, 34*(3), 283-298. doi: 10.1080/13674580802003540

Wilson, S. M., Shulman, L. S., & Richert, A. E. (1987). "150 different ways" of knowing: Representations of knowledge in teaching. In J. Calderhead (Ed.), *Exploring Teachers' Thinking* (pp. 104-204).

Wolfe, P. (1987). What the "seven-step lesson plan" isn't. *Educational Leadership, 44*(5), 70-71.

Wolff, C. E., van den Bogert, N., Jarodzka, H., & Boshuizen, H. P. (2015). Keeping an eye on learning differences between expert and novice teachers' representations of classroom management events. *Journal of Teacher Education, 66*(1), 66 - 85.

Wong, S. S., & Luft, J. A. (2015). Secondary science teachers' beliefs and persistence: A longitudinal mixed-methods study. *Journal of Science Teacher Education, 26*(7), 619-645. doi: 10.1007/s10972-015-9441-4

Wood, C., & Breyfogle, B. (2006). Interactive demonstrations for mole ratios and limiting reagents. *Journal of Chemical Education, 83*(5), 741 - 748.

Wright, B. D. (1996). Time 1 to time 2 (pre-test to post-test) comparison and equating: Racking and stacking. *Rasch Measurement Transactions, 10*(1). Retrieved from: http://www.rasch.org/rmt/rmt101f.htm

Wright, B. D. (2003). Rack and stack: Time 1 vs. Time 2 or pre-test vs. Post-test. *Rasch Measurement Transactions, 17*(1). Retrieved from: http://www.rasch.org/rmt/rmt171a.htm

Wu, C.-H. (2007). An empirical study on the transformation of Likert-scale data to numerical scores. *Applied Mathematical Sciences, 1*(58), 2851-2862.

Yaron, D., Leinhardt, G., & Karabinos, M. (2004). *Shape, transformation, and energy: critical resources for thinking in Chemistry*. SCALE Chemistry Concept Paper. Unpublished manuscript, University of Pittsburgh, Pittsburgh, PA.

Yerrick, R., Parke, H., & Nugent, J. (1997). Struggling to promote deeply rooted change: The" filtering effect" of teachers' beliefs on understanding transformational views of teaching science. *Science Education, 81*(2), 137-159.

Yorks, L. (2005). Adult learning and the generation of new knowledge and meaning: Creating liberating spaces for fostering adult learning through practitioner-based collaborative action inquiry. *Teachers College Record, 107*(6), 1217-1244.

Zaragoza, C., & Fernández-Novell, J. (2008). Teaching chemistry through history: The importance of the periodic table. In J. R. Bertomeu-Sánchez, D. T. Burns, & B. Van Tiggelen (Eds.), *Neighbours and Territories the Evolving Identity of Chemistry: Proceedings of the 6th International Conference of the History of Chemistry* (pp. 685-693). Louvain-la-neuve, Belgium: Mémosciences Asbl.

Zeller, N. (1995). Narrative strategies for case reports. *International Journal of Qualitative Studies in Education, 8*(1), 75-88. doi: 10.1080/0951839950080108

Zimmerman, G. J. (2016). *The design and validation of an instrument to measure the topic specific pedagogical content knowledge of physical sciences teachers in electric circuits.* (Master's research report), University of the witwatersrand, Johannesburg South Africa. Retrieved from http://wiredspace.wits.ac.za/handle/10539/19626