

https://dspace.org/

Exploring the link through which PGCE student teachers' topic specific PCK is transferred in planning, into enactment and into influencing learner outcomes

Makhechane, Mamohato Violet

2021
https://hdl.handle.net/10539/31843

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

EXPLORING THE LINK THROUGH WHICH PGCE STUDENT TEACHERS' TOPIC SPECIFIC PCK IS TRANSFERRED IN PLANNING, INTO ENACTMENT AND INTO INFLUENCING LEARNER OUTCOMES

Mamohato Violet Makhechane
Student Number: 1304503
Supervisor: Professor Elizabeth Mavhunga

A thesis submitted to the Faculty of Humanities,

University of the Witwatersrand, Johannesburg, in fulfilment of

the requirements for the degree of

Doctor of Philosophy

Johannesburg, South Africa

2021

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).

DECLARATION

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



(Signature of candidate)

8th day of February 2021

ABSTRACT

In response to the high demand for teachers in Africa and internationally, non-graduate teaching bachelor's degree holders are recruited into the teaching profession. While they are considered to have high content knowledge (CK) from their previously acquired bachelor's degrees, their lack of pedagogy leaves them with little or no understanding of pedagogical transformation of that CK. Therefore, an investigation of the development of their knowledge for teaching this CK was important. In science education, the construct of Pedagogical Content Knowledge (PCK) has been agreed upon as a construct that blends both the CK and Pedagogical Knowledge (PK), enabling the pedagogical transformation of content knowledge into forms that the learners can comprehend, thus improving classroom instruction. This study investigated the influence of an intervention on the development of physical sciences Postgraduate Certificate in Education (PGCE) pre-service teachers 'Topic Specific PCK (TSPCK) in the topic of Chemical Equilibrium. It focused on tracking the development of their TSPCK from the context of planning to teach, its enactment in the actual classroom teaching and how this enactment influenced learner outcomes in the same topic. The study employed a mixed method (MM) research design of a cohort of 8 PGCE pre-service teachers (PPSTs) registered for a physical science (chemistry) methodology course that aimed at developing their knowledge for teaching, using a TSPCK construct. Applying a case study as a research strategy, the whole class of 8 PPSTs formed a case that enabled the study to describe the quality of planned TSPCK. The cohort was exposed to an explicit TSPCK intervention that ran over 6 weeks. The intervention focused on developing the PPSTs' TSPCK using five content-specific knowledge components for the pedagogical transformation of content knowledge on the topic of Chemical Equilibrium. For this entire group, data were collected through the pre- and post-TSPCK tests and content representations (CoRes)before and immediately after the intervention. Then, a subset of 3PPSTs from the whole class was followed into the classroom where each of them taught two lessons each on Chemical Equilibrium. A subset of 3 PPSTs formed 3-mini cases with 3 classes of learners from 3 different high schools. Data collected at this stage were: the video-recorded lessons of the PPSTs; lesson interviews and stimulated recall interviews conducted with each of the PPSTs after the lessons; and finally, the pre-and post-learner achievement tests and learners' views about the lessons. Data from the 3 mini cases enabled the study to describe the quality of enacted TSPCK and the resultant learner outcomes. The analysis happened in four different stages. Firstly, the PPSTs' TSPCK tools and CoRes were analyzed for planned TSPCK. Secondly, the observed lessons, corroborated with interviews were analyzed for enacted TSPCK. An in-depth qualitative analysis was followed to analyze for the moments of interactive use of TSPCK components in TSPCK tools, CoRes, and lesson observations. Thirdly, the learner- achievement tests were marked with a memorandum of correct answers and analyzed for significant difference through the Rasch Analysis Model and Wilcoxon signed-rank test. Fourth, the relationship between PPSTs' enacted TSPCK and learner achievement were estimated by calculating the Pearson correlation coefficient. The analysis of TSPCK tests and Cores revealed a significant improvement in the quality of the PPSTs' planned TSPCK following the intervention.

Secondly, the PPSTs' lessons demonstrated a high quality of TSPCK enacted in their teaching, with TSPCK episodes categorized mainly at proficient and sophisticated levels. Finally, the analysis revealed a significant positive correlation between the PPSTs' enacted TSPCK and learner performance following the PPSTs' teachings. The correlation increased in positive strength with sophisticated TSPCK episodes emerging from the PPSTs' teachings. The findings suggest that an explicit use of the TSPCK construct can be used to train pre-service teachers (specifically PGCEs) whose teaching can efficiently stimulate the learning process and positively impact on learner performances. The study acknowledges the limitation brought about by the small sample size. Therefore, the findings cannot be generalized. However, the findings of this study suggest that the intervention has a potential to bridge the gap that exists between expert and novice teachers' ability to teach for understanding, and thus produce high quality teachers needed in developing countries including South Africa.

Keywords

Topic Specific Pedagogical Content Knowledge, Chemical Equilibrium, Postgraduate Certificate in Education (PGCE) Pre-service teachers**,** Pedagogical transformation competence, learner achievement.

DEDICATION

This work is dedicated to my loving husband, Tebello, for patience and encouragement throughout this journey. My late parents, Simon and ‘Malerato Nyamane; you are forever in my heart. Finally, all the Glory is given to Father God.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisor, Professor Elizabeth Mavhunga for her unwavering support, her patience, motivation, and immense knowledge. Her guidance and words of encouragement helped me to grow in my research writing. I cannot imagine having a better supervisor. May your wealth of knowledge continue to shine.

A great ‘thank you’ goes to the PGCE pre-service teachers and all the high school learners who willingly participated in this study and never complained. Many thanks also go to Dr. Brighton, Dr. Akinyemi and the entire TSPCK team for invaluable assistance during the course of data collection and validation.

Without the financial support of the National Research Foundation (NRF) funding under Professor Elizabeth Mavhunga, which offered me a scholarship, this work would not have been possible. I am sincerely grateful for the support.

My gratitude is extended to all those who directly and indirectly afforded a helping hand towards the completion of this thesis. May the Good LORD continue to shower you with blessings.

A profound gratitude goes to my loving husband and family for their encouragement and support. My friends and colleagues at the University of Witwatersrand made my stay and studies enjoyable. I am extremely grateful.

Table of Contents

Copyright Notice ..... **i**

Declaration ..... **ii**

Abstract ..... **iii**

Dedication ..... **v**

Acknowledgements ..... **vi**

List of Appendices ..... **x**

List of Figures ..... **xii**

List of Tables ..... **xv**

CHAPTER 1: INTRODUCTION TO THE STUDY **1**

1.0. Introduction **1**

1.1. Background and context of the study **2**

1.2. Statement of the problem **4**

1.3. Rationale for the study **5**

1.4. Research questions **7**

1.5. Conceptual Framework **8**

1.6. Overview structure of the thesis chapters **8**

CHAPTER 2: LITERATURE REVIEW **9**

2.0. Introduction **9**

2.1. Initiatives in science teacher education towards producing effective teachers **9**

2.2. PCK as a knowledge base for Teachers **11**

2.3. Multidimensional nature of PCK **13**

2.4. PCK studies with PGCE pre-service teachers **15**

2.5. Theoretical framework **17**

2.6. PCK quality through an interplay of knowledge components **21**

2.7. Capturing and measuring the quality of PCK **23**

2.8. Understanding the cPCK-plPCK-ePCK trajectory link to learner outcomes **26**

2.8.1. The cPCK-plPCK-ePCK trajectory **26**

2.8.2. Teacher PCK and learner outcomes **29**

2.9. Teaching and learning of Chemical Equilibrium **32**

2.9.1. Alternative conceptions and difficulty associated with the teaching and learning of Chemical Equilibrium **33**

CHAPTER 3: METHODOLOGY **35**
3.0. Introduction **35**
3.1. Research Methodology and Design **36**
3.2. Research strategy **38**
3.2.1. Case study **38**
3.3. Participant selection/Sampling **39**
3.4. The Intervention **42**
3.5. Tools and Instruments **43**
3.6. Data Collection **49**
3.7. Data Analysis **53**
3.7.1. Analyzing for the extent of the development of the PPSTs' TSPCK in planning **55**
3.7.2. Analyzing for evidence of TSPCK in a teaching context **61**
3.7.3. Analyzing for the link between the PPSTs' eTSPCK and learner outcomes **64**
3.8. Trustworthiness and Validity **68**
3.8.1. Qualitative method **68**
3.8.2. Quantitative method **71**
3.9. Limitations **71**
3.10. Ethical Considerations **72**
CHAPTER 4: THE TSPCK BASED INTERVENTION WITH THE PGCE PRE-SERVICE TEACHERS **73**
4.0. Introduction **73**
4.1. Explaining the rationale for conducting the intervention **73**
4.2. Describing the structure/outline of the intervention **75**
4.2.1. The intervention sessions – Introduction session **77**
4.2.2. Learner prior knowledge including misconceptions **78**
4.2.3. Curricular Saliency sessions **81**
4.2.4. What is difficult to understand and teach? **84**
4.2.5. Sessions on use of representations **87**
4.2.6. Discussions on conceptual teaching strategies **90**
4.2.7. Pulling components together **92**
4.2.8. An introduction of a CoRe **93**
4.2.9. Evaluation of the construct **93**
4.3. Conclusion **94**

CHAPTER 5: THE DEVELOPMENT OF PLANNED TSPCK FOR PGCE PRE-SERVICE TEACHERS 96
5.0. Introduction **96**
5.1. Shifts in the quality of PPSTs' planned TSPCK **98**
5.1.1. Individual PPST's average/proxy TSPCK development **100**
5.1.2. The group average/proxy TSPCK development per component **104**
5.1.2a. A closer look into individual components; the meaning behind the scores **108**
5.1.2b. TSPCK development shift across all the components: *shift by one teacher* **132**
Conclusion **140**
CHAPTER 6: ANALYSIS OF PGCE PRE-SERVICE TEACHERS' ENACTED TSPCK 142
6.0. Introduction **142**
6.1. Analysis **143**
6.1.1. A detailed description of the analysis **144**
6.2. Understanding the pre-service teachers' enacted TSPCK (eTSPCK) **144**
6.2.1. Overview of the lessons by the subset of 3 PPSTs **144**
6.2.2. Overview of the Findings **148**
6.2.1. An in-depth analysis of the PPSTs' lessons **153**
6.3. The Findings **177**
6.3.1. Revealing the complex and idiosyncratic nature of TSPCK component interactions **177**
6.3.2. TSPCK episodes portrayed in the lesson plans versus those in the lesson observations **183**
6.3.3. Lesson episodes triggered by learners' questions or responses to the questions asked by the PPSTs **196**
6.3.4. The teaching segments entailing difficult concepts and or common learner misconceptions mainly proficient and sophisticated **197**
6.5. Summary **199**
CHAPTER 7: MEASURING THE IMPACT OF PPSTs' TEACHING ON LEARNERS' PERFORMANCE IN CHEMICAL EQUILIBRIUM 201
7.0. Introduction **201**
7.1. Brief Summary on Methodology **201**
7.1.1. The structure of the learners' achievement tests **202**
7.1.2. Analysis of the learners' performance tests **203**
7.2. Quantitative Findings on Learners' achievement in Chemical Equilibrium **204**

7.2.1 An overview finding of learners' performance (ordinal raw scores) **204**
7.2.2. Quantitative in-depth analysis of the learners' achievement per PPST..... **205**
7.3. Summary of the key findings in this Chapter..... **230**
CHAPTER 8: UNDERSTANDING THE CORRELATIONS BETWEEN TEACHER KNOWLEDGE AND LEARNER PERFORMANCE **232**
8.0. Introduction **232**
8.1. A Brief Summary on Methodology..... **233**
8.1.1. Data Analysis..... **234**
8.2. eTSPCK and learner performance correlation analysis **234**
8.2.1. Quantitative overview patterns of the correlation analysis between the PPSTs' eTSPCK episodes and learner performance **234**
8.3. Summary of key the findings in this Chapter..... **262**
CHAPTER 9: DISCUSSION AND IMPLICATIONS..... **267**
9.0. Introduction **267**
9.1. Establishing a credible baseline of the study: plTSPCK acquired from a cTSPCK based intervention..... **268**
9.2. Contributions to New Knowledge..... **270**
9.2.1. The development of PPSTs' plTSPCK and eTSPCK **271**
9.2.2. The correlation between PPSTs eTSPCK and learner outcomes **275**
9.2.3. The cTSPCK-plTSPCK-eTSPCK trajectory link to learner outcomes **282**
9.2.4. Reflection on elements that exposed the quality of the PPSTs' TSPCK by the learners **283**
9.3. Summary of research questions..... **285**
9.4. Conclusion..... **288**
9.5. Implications and recommendations of the study..... **288**
9.6. Critical reflections of the research process **290**
9.6.1 Collective TSPCK: Reflection on the intervention **290**
9.6.2. Reflections on the research methodology used **292**
9.6.3. Validity and Trustworthiness..... **294**
9.7. Limitations of the study..... **294**
9.8. Future Research..... **295**
References **297**

LIST OF APPENDICES

Appendix A: TSPCK tool in Chemical Equilibrium 312
Appendix B: Content Representation (CoRe)..... 322
Appendix C: An interview protocol..... 323
Appendix D: Achievement test on Chemical Equilibrium (with marking memo) 324
Appendix E: Questions for collecting the learners' views about the pre-service teachers..... 333
Appendix F: A rubric for measuring planned TSPCK..... 334
Appendix G: A rubric for measuring enacted TSPCK 335
Appendix H: Ethics Clearance report 336
Appendix I: GDE Approval..... 337
Appendix J: Consent form to the Head of School 338
Appendix K: Consent form to the Course Coordinator 340
Appendix L: Consent form to the Course Lecturer 342
Appendix M: Consent form to the PGCE pre-service teachers 344
Appendix N: Consent form to the Principals..... 347
Appendix O: Consent form to the Supervising teacher 349
Appendix P: Consent form to the Parents..... 351
Appendix Q: Consent form to the Learners..... 353
Appendix R: A detailed analysis of Noma's lesson..... 355
Appendix S: A detailed analysis of Lerato's lesson 363
Appendix T: Sara's lesson plan 374
Appendix U: Noma's learner Rasch Person and Item Measure (Pre-and post-test)..... 379
Appendix V: Noma's TSPCK episode Rasch Person Measure 380
Appendix W: Lerato's learner Rasch Person and Item Measure (Pre-and post-test) 381
Appendix X: Lerato's TSPCK episode Rasch Person Measure 382
Appendix Y: Sara's learner Rasch Person and Item Measure (Pre-and post-test) 383
Appendix Z: Sara's TSPCK episode Rasch Person Measure 384

LIST OF FIGURES

Figure 2. 1: Refined Consensus Model of PCK (Carlson & Daehler, 2019, p. 83) 17
Figure 2. 2: Simplified positioning of TSPCK in the refined consensus model of PCK (Mavhunga and van der Merwe, 2020) 20
Figure 3. 1: A TSPCK tool extract on chemical equilibrium 45
Figure 3. 2: Questions on learners' views 47
Figure 3. 3: Procedural summary of data collection steps 50
Figure 3. 4: Summary structure of the analysis chapters 54
Figure 3. 5: An extract for the rubric for quantifying PCK (Mavhunga & Rollnick, 2013) 56
Figure 3. 6: A TSPCK episode extract on what is difficult to understand: an extract from a TSPCK tool 57
Figure 3. 7: A Tutorial extract by Jane and Sara on addressing a learner misconception 59
Figure 4. 1: Sara and Jane's response on common learner misconceptions 79
Figure 4. 2: Daniel and Mandla's misconception interpretation 80
Figure 4. 3: PGCE Pre-service teacher responses on a component of curricular saliency 83
Figure 4. 4: A response on what is difficult for learners to understand 85
Figure 4. 5: Concentration and rate versus time graphs 87
Figure 4. 6: Examples of multiple representation use to explain a concept 88
Figure 4. 7: A rate and concentration versus time graphs 91
Figure 4. 8: Equations on the calculation of equilibrium constant (Kc) 92
Figure 4. 9: PPSTs' responses on their overall views about the intervention 94
Figure 4. 10: Pre-service teachers' anonymous comments on their gains on the course 94
Figure 5. 1: Average shifts in pre and post individual scores 100
Figure 5. 2: Graphical representations of individual PPSTs' pre and post-TSPCK scores 102
Figure 5. 3: The shift in quality across all TSPCK components 104
Figure 5. 4: The group average TSPCK scores across all components 106
Figure 5. 5: A TSPCK tool extract on chemical equilibrium 109
Figure 5. 6: Jane's qualitative data responses in the component of learner prior knowledge 110
Figure 5. 7: An extract on curricular saliency from the TSPCK test on chemical equilibrium 115
Figure 5. 8: Sara's responses in the pre (post) TSPCK tests in the component of curricular saliency 116
Figure 5. 9: Lerato's responses in the pre-post TSPCK tests and post CoRe in the component of representations 120
Figure 5. 10: Daniel's responses in the pre (post) TSPCK tests in the component of what is difficult to understand/teach 125
Figure 5. 11: An extract on conceptual teaching strategies from the TSPCK test on chemical equilibrium 129
Figure 5. 12: Mandla's responses in the pre (post) TSPCK tests in the component of conceptual teaching strategies 130
Figure 5. 13: Sara's planned TSPCK profile on Chemical Equilibrium 132
Figure 5. 14: Sara's TSPCK development in the five content knowledge transformation components across the intervention 139

Figure 6. 1: The participants' action TSPCK profiles 152
Figure 6. 2: A pictorial display of PSTs' TSPCK episodes in the sequence of their emergence 154
Figure 6. 3: PGCE PSTs' TSPCK profiles displaying their lesson sequence..... 176
Figure 6. 4: Extracts on the actual teaching of the types of systems 182
Figure 6. 5: An overview of Noma's TSPCK; lesson plans versus lesson enactment..... 185
Figure 6. 6: Noma's lesson plan extract and enactment on reversibility of chemical reactions. 186
Figure 6. 7: An overview of Noma's lesson plan versus her enacted TSPCK episodes for the first lesson 188
Figure 6. 8: An overview of Lerato's TSPCK; lesson plans versus lesson enactment..... 189
Figure 6. 9: Lerato's lesson plan extract and enactment on types of systems 190
Figure 6. 10: Lerato's lesson 1 on conditions for Chemical Equilibrium..... 192
Figure 6. 11: An overview of Sara's TSPCK; lesson plans versus lesson enactment 193
Figure 6. 12: Sara's lesson plan extract and enactment introducing factors that affect an equilibrium state 194
Figure 6. 13: Sara's lesson 1 on conditions for chemical equilibrium..... 195
Figure 7. 1: Noma's learner-Gelo's pre and post-test written response for item 4..... 209
Figure 7. 2: Noma's learner- Keam's pre and post-test written response for item 4..... 210
Figure 7. 3: A variable map for Noma's learners pre- and post-achievement test Rasch measures 212
Figure 7. 4: Summary for the calculation of significance difference for Noma's learners' performances 214
Figure 7. 5: Lerato's learner Eman's pre and post-test written response for item 11..... 219
Figure 7. 6: Lerato's learner Meli's pre and post-test written response for item 11..... 219
Figure 7. 7: A variable map for Lerato's learners pre- and post-achievement test Rasch measures 220
Figure 7. 8: Summary for calculation of significance difference for Lerato's learners' performances 222
Figure 7. 9: Sara's learners' pre and post-test written responses for item 9..... 226
Figure 7. 10: A variable map for Sara's learners pre- and post-achievement test Rasch measures 228
Figure 7. 11: Summary for the calculation of significance difference for the performance of Sara's learners..... 229
Figure 7. 12: The summarized content gains on Chemical equilibrium concepts across the PPSTs' learners..... 231
Figure 8. 1: Overall correlation between the PPSTs' eTSPCK and learner performances..... 235
Figure 8. 2: Noma's overall eTSPCK episodes and her learners' Rasch Person measures..... 241
Figure 8. 3: Noma's teaching segment on the effect of a disturbance at Chemical Equilibrium 243
Figure 8. 4: Learner Gelo's written responses on item 4 of learners' achievement tests 244
Figure 8. 5: Learner Keam's written responses on item 4 of learners' achievement tests 245
Figure 8. 6: Lerato's overall eTSPCK episodes and his learners' Rasch Person measures..... 249
Figure 8. 7: Lerato's teaching segment on different types of systems..... 251
Figure 8. 8: Learner Tume's written responses on item 7 of the learners' achievement tests.... 252
Figure 8. 9: Learner Toka's written responses on item 7 of learners' achievement tests..... 252

Figure 8. 10: Sara's overall eTSPCK episodes and her learners' Rasch Person measures 256
Figure 8. 11: Sara's teaching segment on dynamic Chemical Equilibrium..... 259
Figure 8. 12: Sara's learners' written responses on item 9 of learners' achievement tests 260
Figure 8. 13: The written responses of Sara's learners on item 9 of the learners' achievement tests 261
Figure 8. 14: Overall eTSPCK episodes identified from the PPSTs' teachings..... 262
Figure 8. 15: Summative correlation analysis per each PPST 264
Figure 8. 16: A summary of the relationship between the PPSTs' sophisticated TSPCK and learner performances 265

LIST OF TABLES

Table 3. 1: A Table of characteristic features of the PPSTs participating in this study 41
Table 3. 2: Information about the participant learners (N=43) 42
Table 3. 3: Description of the content covered in the learner-achievement test 46
Table 3. 4: TSPCK rubric for scoring TSPCK in action (Miheso, 2018) 62
Table 3. 5: Guidelines for interpreting the size of correlation coefficient (Hinkle et al., 2003) .. 66
Table 3. 6: Summary of the Research Design 68
Table 4. 1: Content and structure of the intervention in a Chemistry methodology course 76
Table 5. 1: Raw pre- and post-intervention TSPCK-test scores (N=8) 99
Table 6. 1: The participants personal TSPCK and years of obtaining previous degree 143
Table 6. 2: A general context for Noma's lessons 144
Table 6. 3: A general context for Lerato's lessons 146
Table 6. 4: A general context for Sara's lessons 147
Table 6. 5: The nature of the TSPCK component interactions in the identified TSPCK episodes 149
Table 6. 6: The frequency of TSPCK component interactions in the identified TSPCK episodes 151
Table 6. 7: A detailed analysis of Sara's lesson 156
Table 6. 8: Overview on the nature of TSPCK episodes and component interactions from the PPSTs lessons 178
Table 6. 9: Types and nature of episodes in lesson plans 184
Table 7. 1: Important information about the participant PPSTs and their learners 202
Table 7. 2: Description of the content covered in the test 203
Table 7. 3: Learners' raw scores on pre-and post-tests displayed 204
Table 7. 4: Learners' content knowledge gains on chemical equilibrium concepts: Noma's class 205
Table 7. 5: The person Rasch scores of the pre- and post-achievement test of Noma's learners 206
Table 7. 6: Ranked Rasch item measures for Noma's learners' pre-and post-achievement tests 208
Table 7. 7: Pre and Post-test rank order Rasch measures for the items compared 209
Table 7. 8: Stacked data- Person measures from anchored pre-and post-test 214
Table 7. 9: Displaying learners' content knowledge gains on chemical equilibrium concepts: Lerato's class 215
Table 7. 10: The person Rasch scores of the pre- and post-achievement test of Lerato's learners 216
Table 7. 11: Ranked Rasch item measures for Lerato's learners' pre-and post-achievement tests 217
Table 7. 12: Pre and Post-test rank order Rasch measures for the items compared 218
Table 7. 13: Stacked data- Person measures from anchored pre-and post-test 221
Table 7. 14: Displaying learners' content knowledge gains on chemical equilibrium concepts: Sara's class 223

Table 7. 15: The Rasch person scores of the pre- and post-achievement test for Sara's learners 224
Table 7. 16: Ranked Rasch item measures for Lerato's learners' pre-and post-achievement tests 225
Table 7. 17: Pre and Post-test rank order Rasch measures for the items compared 225
Table 7. 18: Stacked data- Person measures from anchored pre-and post-test..... 229
Table 8. 1: The key information about the participant PPSTs and their learners 233
Table 8. 2: Noma's eTSPCK episodes converted into Rasch person measures 238
Table 8. 3: Noma's learners' Rasch person measures imported as Table 7.5 in Chapter 7..... 240
Table 8. 4: Noma's eTSPCK episodes against her learners' conceptual performances 242
Table 8. 5: Lerato's eTSPCK episodes converted into Rasch person measures..... 247
Table 8. 6: Lerato's learners' Rasch person measures imported as Table 7.10 in Chapter 7 248
Table 8. 7: Lerato's eTSPCK episodes against his learners' conceptual performances..... 250
Table 8. 8: Sara's eTSPCK episodes converted into Rasch person measures 254
Table 8. 9: Sara's learners' Rasch person measures imported as Table 7.15 in Chapter 7 255
Table 8. 10: Sara's eTSPCK episodes against her learners' conceptual performance 257

ABBREVIATIONS

PGCE	Postgraduate Certificate in Education
PSTs	Pre-service teachers
PPSTs	Postgraduate Certificate in Education Pre-service teachers
PCK	Pedagogical Content Knowledge
cPCK	Collective Pedagogical Content Knowledge
pPCK	Personal Pedagogical Content Knowledge
plPCK	Planned Pedagogical Content Knowledge
ePCK	Enacted Pedagogical Content Knowledge
cTSPCK	Collective Topic Specific Pedagogical Content Knowledge
pTSPCK	Personal Topic Specific Pedagogical Content Knowledge
plTSPCK	Planned Topic Specific Pedagogical Content Knowledge
eTSPCK	Enacted Topic Specific Pedagogical Content Knowledge
CK	Content Knowledge
TSPCK	Topic Specific Pedagogical Content Knowledge
PTC	Pedagogical Transformation Competence

CHAPTER 1

INTRODUCTION TO THE STUDY

This Chapter introduces the study within the context of South African science classrooms. The importance of developing science teachers 'knowledge that can effectively enhance learner performances is also explained. Further information on the purpose and rationale of the study are given, including research questions that guided the study. The chapter closes with an overview of all the chapters in this thesis.

1.0. Introduction

There has been a debate in the literature on whether teaching is in fact a natural phenomenon which does not necessarily have to be learned through schooling (Malikow, 2006; Ball & Forzani, 2009; Strauss, Calero & Sigman, 2014). The debate includes whether the saying, "teachers are born" is a reality and whether content knowledge alone is enough to result in high quality and effective teaching. While Strauss and Ziv (2012) are of the view that teachers are born, other researchers argue that, although there are some "exceptional teachers" born with special personality traits, some forms of knowledge and skills in the teaching profession can only be obtained through teacher training (Malikow, 2006; Ball & Forzani, 2009). In support of their argument is the literature that points to studies that have indicated that mathematics and science practitioners do not necessarily deliver lessons for learner understanding (Rollnick, Davidowitz & Potgieter, 2017; Ball & Forzani, 2009). This implies that a Bachelor of Science degree holder who attained very good grades in her/his undergraduate or even postgraduate degree may not necessarily excel in the art of teaching science. Such individuals may need to have formal educational courses that will equip them with some pedagogies of effective teaching that can enable them to effectively teach their CK to the learners. This study aligns more with the view that teachers are made and not to rely on natural gifts (Malikow, 2006). What influenced this position are the studies that have been done with science pre-service teachers (PSTs) indicating the improvement in professional teacher knowledge for teaching science with understanding by the learners called Pedagogical Content Knowledge (PCK) (Rollnick & Mavhunga, 2016; Akinyemi, 2020). PCK is known to be developed in teachers with elongated time of a reflective practice. The observed improvement in the quality of teaching for understanding by the PSTs is indicative of a direct result of being taught systematically and thoughtfully how to teach. This makes it necessary to want to investigate and

understand how teachers' professional knowledge may be developed through a process of learning to teach, its manifestation in the actual teaching context and its influence on learner outcomes.

1.1. Background and context of the study

There is a common practice around the world, where graduates of non-teaching bachelors' degree are recruited into the teaching profession in order to meet the demand for teachers for a specific discipline (Roness & Smith, 2009; Barth, Dillon, Hull, & Higgins, 2016). Often, there are different reasons for the teacher demand, including the fact that the teacher preparation institutions do not produce sufficient numbers of teachers needed in the schools (Ingersoll & Perda, 2009) and do not produce a sufficient number of science teachers of high quality (Kind, 2016).This is also pointed out by Ogunniyi and Rollnick (2015) who argued that, this is one of the challenges that African countries are faced with, that they are unable to produce and retain a sufficient number of qualified science teachers. The state of science education in less developed countries such as South Africa is a worry to many. The presence of unqualified or insufficient science teachers in schools could be associated with the low performance of the learners in science subjects. The Trends in International Mathematics and Science Study (TIMSS) 2011 results confirmed the poor education level in South African schools when it was discovered that in KwaZulu-Natal the Grade 9 learners' level of understanding and learning ability for science was 2.5 years lower than that of the learners in the same grade in Western Cape who, in turn, were also 1.8 years behind those in Gauteng and other countries (Spaull, 2013).This indicates disparity nationally and internationally (Spaull, 2013).Also showing inequality in education between different provinces is the indication that in 2011 only 20 percent of the 2001 grade 2 cohort passed grade NSC examination in Eastern Cape as opposed to 60 percent in Gauteng. Likewise, the South African Progress in International Reading Literacy Study (PIRLS) 2011 showed that the literacy for grade 4 learners from rural and township areas was found to be 2 to 2½years behind those in the urban areas (Howie, Van Staden, Tshele, Dowse, & Zimmerman, 2012; Martin, Mullis, Foy, & Stanco, 2012).The reason for the portrayed inequality could be associated with the findings by Bertram and colleagues that South African schools in the rural areas are occupied by unqualified teachers (Bertram, Mthiyane & Mukeredzi, 2013).Multiple other factors have been attributed to the observed poor learner performance in mathematics and science in South African schools. These include: the shortage of qualified science teachers in South Africa (Bertram *et al.,* 2013), inadequate teachers' content

knowledge (Spaull, 2013; Modisaotsile, 2012), poor instructional strategies (Makgato & Mji, 2006), and teachers' poor quality of PCK (Rollnick, 2017). According to Modisaotsile (2012), some of these challenges emanate from poor teacher training. The National Policy Framework for Teacher Education and Development (Department of Higher Education and Training, 2015) also acknowledged that poor conceptual knowledge and instructional strategies were found among high school teachers. The policy calls for initial teacher training programmes to develop courses that promote acquisition, integration, and application of knowledge in PSTs. This includes, among other things: development of subject matter knowledge, pedagogical learning which constitutes general pedagogical knowledge and specialized pedagogical content knowledge, practical learning and the use of information and communication technology (ICT) learning (Department of Higher Education and Training, 2015). The policy aims to ensure that the PSTs are equipped with adequate pedagogical competence in subject matter knowledge and instructional strategies that facilitate learning.

To recruit more science teachers into the education system, different countries including South Africa, have opted for short courses such as the Postgraduate Certificate in Education (PGCE) that different science related bachelor's degree candidates can use as the bridges into the system. PGCE is a one-year full-time or a two-year part-time course of professional training for teaching which is recognized around the world (Hodgson, 2014; Ping, 2013). On acquiring PGCE, the graduates are then given a Qualified Teacher Status (QTS). Thus, the purpose of PGCE has been 'to accredit a generalist educator's qualification that caps an undergraduate qualification' (Mahomed & Singh, 2011, p. 504). It accommodates individuals who have obtained bachelor's degrees at undergraduate level and wish to direct their careers into the teaching profession. The PGCE pre-service teacher (PPSTs) programme only focuses on developing their knowledge for teaching (including PCK) with little attention paid to the content knowledge (Bayaga, 2010; Murekedzi, Mthiyane & Bertram, 2015).This assumes that they bring enough content knowledge from their previous Bachelor degrees (Hirst, 1980; Ogunniyi & Rollnick, 2015).This is in accordance with the understanding in the PCK literature that the development of teachers' PCK requires a rich understanding of the subject matter which is argued to be a pre-cursor to PCK growth (Cooper, Loughran, & Berry, 2015; Pitjeng-Mosabala & Rollnick, 2018).The development of PCK involves the blending of both content knowledge and pedagogical knowledge, as teachers transform their subject matter knowledge into forms more accessible to the learners (Shulman, 1986).Therefore,

the PCK construct is considered, in science education, as one effective domain of teacher knowledge that can help PSTs to learn about the complexity of teaching and learning process. Investigating the development of the PPSTs' knowledge for teaching (PCK), including how this knowledge manifests itself in the context of classroom teaching and its influence on learner understanding, therefore becomes a necessity.

1.2. Statement of the problem

Martinet al. (2012: 48) observed that:

"There was evidence of many very low performing ninth grade students in South Africa, with the percentage of students with achievement too low for estimation between 15 percent and 25 percent."

Every education system requires qualified, sophisticated teachers of high quality if it is to be successful. An insufficient number of qualified physical science teachers of high quality in South African high schools is one of the problems that the country is facing (Ramnarain & Fortus, 2013). It is due to this insufficiency that the participation by the country in this fast changing scientific and technology world seems to be limited. In particular, Stutchbury (2014) argues that "too many children are emerging from school without the education that they need", (p. 1). Makgato and Mji (2006) attribute the learners' poor performance in mathematics and physical science in South Africa to the teachers' incompetence (minimal content knowledge and choice of instructional strategies). This implies that the teachers' ability to transform their content into teachable forms for improved accessibility by the learners is a challenging factor, with a negative impact on the learners' understanding and their performance in the subjects.

As we continue in South Africa to train teachers through two main streams, one being a 4-year B Ed degree and the other being the PGCE stream where teacher trainees undergo a one-year fulltime teacher training programme, the concern arises about the adequacy of their training. For South Africa to survive this tragedy of poor learner performance in science, it needs qualified teachers who are knowledgeable in science and have been taught accordingly so. Initial teacher training institutions are therefore under pressure to produce science teachers who are highly motivated, hardworking and of high quality, who can teach for learner understanding and thus improve the quality of education that South Africa needs (Witzig & Sickel, 2017). Fisher and Scott (2011)

argued that "higher education has a uniquely important role in resolving the persistent skills shortage in South Africa by producing qualified graduates and postgraduates" (p.1). Therefore, unless teacher training institutions begin to understand the core practices needed by PGCE as a special group of pre-service teachers and also understand the ways in which this group learns, transfers and uses its knowledge, the production of high caliber physical science teachers (as needed by the current crisis) will remain a dream. Poor learner performance in physical science may persist and the country may never be able to produce enough scientists, of its own, who will contribute towards the economic development as desired.

1.3. Rationale for the study

Research has indicated that African countries are unable to produce a sufficient number of qualified science teachers (Ogunniyi & Rollnick, 2015). Ramnarain and Fortus (2013) also confirmed that in South Africa there are not enough physical science teachers of high quality. This situation implies that the newly qualified teachers are expected to deliver sound science lessons on arrival at schools. In order to address this situation, researchers have argued for the need to "develop high quality science teacher education programs" to equip teachers with knowledge to deliver high quality teaching that promotes learner conceptual understanding (Witzig & Sickel, 2017, p. 1). In particular, high-quality teaching and learning is characterized by active engagement with the learners. This, in turn, promotes learners' interest and conceptual understanding (Yip, Wong, Yick, Chan & Wong, 2019; Lam & Muldner, 2017). Where PCK has been considered as the knowledge base for teaching (Shulman, 1986) which enables a science teacher to deliver effective lessons, its development in the pre-service teachers training programmes is essential. This is in support of the understanding that PCK develops with elongated time in practice (Chan & Yung, 2017), leaving the novice teachers and hence PSTs, with less-developed PCK. It becomes reasonable therefore to introduce PCK in the pre-service education programmes to produce teachers who can develop meaningful lessons that are accessible to the learners (Kind, 2009). The significance of this is in its ability to fast-track the production of qualified science teachers, particularly for developing countries, such as South Africa, which are burdened with poor learner performance in science. This could be considered as an attempt to improve the quality of education in South Africa (Al-Sherif, 2010; Mthethwa-Kunene, Onwu & de Villiers, 2015), because it is

only through acquisition of such competence that novice teachers would be able to perform their roles effectively and efficiently.

Overall, there is a consensus that PCK is regarded as the professional knowledge for teaching science (Loughran, Mulhall & Berry, 2004) and that it is more visible when considered at a topic level (Abell, 2008). Mavhunga and Rollnick (2013) refer to this kind of PCK as topic specific PCK (TSPCK). These researchers identified five content-related knowledge components of TSPCK as the topic specific components of TSPCK that distinguish it from other grain sizes of PCK (Mavhunga & Rollnick, 2013; Geddis *et al.*, 1993). These components are: (i) learners' prior knowledge including misconceptions, (ii) curricular saliency, (iii) what makes a topic easy or difficult to understand, (iv) representations including analogies and (v) conceptual teaching strategies. In this regard, the quality TSPCK for teaching a specific topic is determined by the extent of the interactive use of TSPCK components to make the content understandable to the learners. This is referred to as the '*pedagogical transformation competence*' (Mavhunga, 2016). Further, there are empirical findings affirming that TSPCK can be taught to PSTs to develop planned TSPCK (plTSPCK) (Mavhunga & van der Merwe, 2020; Akinyemi, 2020). For example, several studies have proven the effectiveness of specific interventions focusing on specific topics to developing such competence in the PSTs (Mavhunga, 2016) and beginning teachers (Pitjeng-Mosabala & Rollnick, 2018) mostly in the context of learning to teach.

This study followed a unique group of participants (PPSTs) who went through the same signature intervention using the TSPCK construct used by Mavhunga and Rollnick (2013). It was intended to equip the participants with competence to transform content knowledge for a specific topic (Chemical Equilibrium). The group is unique in that its exposure to PCK and other pedagogies was limited to a single year, as opposed to the 4-year period common to traditional PSTs. Through this intervention, the PPSTs were introduced to the complexities of teaching and different practices that expert teachers use to maximize learning. While several studies that focused on the traditional B.Ed. PSTs have confirmed the effectiveness of the TSPCK construct in developing the PSTs' plTSPCK (Mavhunga & Rollnick, 2013; Akinyemi, 2020), little is known about how the PPSTs develop their professional knowledge for teaching from the context of learning to teach using the same construct. To fill this gap, the study explored the PPSTs development from their acquisition of TSPCK in Chemical Equilibrium. This study examined how the *competence* learned by the

PPSTs in the context of planning to teach Chemical Equilibrium and manifested in planning, informed the competence displayed in the actual classroom teaching and its influence on the learners' performance. The understanding of how the TSPCK construct can be used in initial teacher training of PPSTs to develop sound personal TSPCK will provide useful information for the design of high-quality science teacher training programmes. It is therefore envisaged that the findings of this study will contribute to finding a solution for the current South African challenge of lack of high-quality science teachers.

1.4. Research questions

Based on the above arguments, the study attempted to respond to the following question: How has the pedagogical transformation competence learned in the context of planning to teach influenced the PGCE pre-service teachers' quality of personal TSPCK seen in planning and actual classroom teaching of Chemical Equilibrium, and the subsequent learner outcomes?

There is an understanding in the PCK literature that the competence to pedagogically transform content knowledge in a specific topic, as mentioned in the main research question, demonstrates the quality of teacher professional knowledge in science called TSPCK. The main research question was therefore explored through the following sub-questions that place emphasis on the extent of pedagogical transformation that could be observed:

Sub-questions

1.0 What is the quality of TSPCK displayed by the PGCE pre-service teachers in their planning for teaching Chemical Equilibrium, following the explicit discussions during the intervention that aimed at developing their knowledge for planning to teach Chemical Equilibrium?

2.0 What is the quality of the PGCE's TSPCK observed in classroom teaching and in what ways does it reflect the observed TSPCK in planning?

3.0 In what ways does the observed PGCE's enacted TSPCK, observed in the classroom, relate to learner performance in Chemical Equilibrium?

1.5. Conceptual Framework

Grounding this study is the theoretical idea proposed by Shulman (1986) that teaching requires transformation of content knowledge through the use of multiple knowledge domains, including the fact that the value of the pedagogically transformed knowledge lies in its positive effect in enhancing learner outcomes (Rollnick & Mavhunga, 2015).This conceptual framework of the study was guided by Mavhunga and van der Merwe's (2020) simplified model that positions topic specific PCK in the refined consensus model (RCM) of PCK. In Chapter 2, I provide a detailed discussion of this framework.

1.6. Overview structure of the thesis chapters

This thesis consists of nine chapters, beginning with an overview of the introduction to the study, which includes the rationale for the study, the description of the research problem, as well as the research questions guiding this study. Chapter 2 presented the literature on the initiatives in science teacher education towards producing effective teachers and relevant PCK literature including PCK studies on PGCE pre-service teachers. This is followed by a discussion on the conceptual framework guiding this study, which is the Refined Consensus Model of PCK and the simplified version positioning TSPCK in the RCM of PCK. The chapter then describes different ways of capturing and measuring PCK, cPCK-pPCK-ePCK learner outcomes link and provides an overview on the teaching and learning of Chemical Equilibrium. Chapter 3 describes the research methodology, which includes the mixed-methods (MM) and a case study design, the research instruments used and the methods of collecting and analyzing data, validity, and reliability of the measures, as well as the issues of ethical consideration. Chapter 4 discusses the intervention conducted in this study, using the TSPCK construct from which the pedagogical transformation competence for planning to teach Chemical Equilibrium emerged. Chapter 5 is the first chapter of analysis on the PPSTs' personal TSPCK (pTSPCK) that manifested in the context of planning to teach as plTSPCK. Chapter 6 presented the analysis of the PPSTs' pTSPCK that manifested in the actual classroom teaching of Chemical Equilibrium (eTSPCK). The analysis of the learners' performance in the achievement tests is discussed in Chapter 7. Chapter 8, which is the last chapter of analysis, discusses the relationship between the PPSTs' eTSPCK and learner achievement in an attempt to establish the TSPCK-learner outcomes link. Chapter 9 summarizes all the findings from the analysis chapters and then presents discussions and the implications of the study.

CHAPTER 2

LITERATURE REVIEW

In this section I review the literature related to the development of pedagogical content knowledge (PCK) in the context of pre-service teacher (PST) education programmes, *PCK in planning, enactment, and learner outcomes. The focus is on the development of pedagogical transformation competence using a TSPCK framework consisting of 5 content-specific knowledge components. The Chapter closes with a review of the cPCK-plPCK-cPCK learner outcome link.*

2.0. Introduction

Grounding this study is the theoretical idea proposed by Shulman (1986) that teaching requires transformation of content knowledge through the use of multiple knowledge domains. This study is also based on the argument that the processes that lead to effective classroom teaching start long before the actual teaching process begins, starting with a comprehensive pedagogical reasoning about the content that the teachers will be teaching (Shulman, 1987) and the value of the pedagogically transformed knowledge which lies in its positive effect in enhancing learner outcomes (Rollnick & Mavhunga, 2015). With PCK, referred to as the amalgam of knowledge components that enables pedagogical transformation (Geddis & Wood, 1997; Shulman, 1987), the PSTs (more specifically, the PPSTs) are also required to develop the skills that will enable them to critically engage with and pedagogically transform the content. The PPSTs are expected to pedagogically engage with and think about the content, teach efficiently, and reflect on the lesson activities which further develop their knowledge for teaching. This study acknowledges the need for the development of PCK in the teacher development (Kind, 2009). Therefore, the review of the literature focuses on the importance of initial teacher programmes. With little known about the effect of PPSTs' PCK on learner outcomes, this study reviews the literature on developing competence that enables effective teaching that ultimately enhances learner outcomes.

2.1. Initiatives in science teacher education towards producing effective teachers

Recently, researchers, specifically on teacher education focus their research studies on the best practices that can be used in teacher education to prepare high quality teachers that are needed by the profession (Dutro & Cartun, 2016). The focus is on the core practices, thus looking specifically at the actual basic classroom teaching practices. They refer to practices as "routine activities

teachers engage in devoted to planning, enactment, or reflection that are intended to support student learning" (Windschitl *et al.*,2012, p. 882). These are common or basic practices fundamental to teaching that teachers enact to support learning which includes strategies, routines and moves that teachers learn and hone to support their teaching and enhance rich learning (Dutro & Cartun, 2016). In other words, the concern is on how these core practices can be used to prepare teachers to improve their teaching skills. The value of this rests in the fact that activities that teachers engage learners in should be conceptually accessible by learners, hence the need for all the teachers to be more knowledgeable in those aspects.

Similarly, Grossman, Hammerness and McDonald (2009) argue on the need for teacher educators to focus their attention on how to help novice teachers to develop skilled practice which, according to McDonald, Kazemi and Kavanagh (2013), may help teachers to learn how to use their acquired knowledge in practice. The aim is to attend to the problem of enactment, by focusing specifically on the common classroom practices essential for effective teaching which is usually practiced by experts in the field. In other words, this can create a connection between theory and classroom practice, thus breaking the theory-practice divide (Mavhunga& van der Merwe, 2020). Most importantly, how teachers are prepared has been argued to substantially impact on how they will teach. This ultimately affects the learner performance (Ball & Forzani, 2009). Consequently, if the aim of researchers in teacher education is to improve learning, then a greater focus should be on how teachers are prepared so that their teaching may enhance learner understanding and, hopefully, their performance. Introducing the core practices in teacher education training programmes can improve the novice teacher instructional practices and thus bridge the gap that exists and can be observed between the teaching of a novice and of an experienced teacher. Inexperienced teachers may quickly begin to teach as experienced teachers do and this may reduce the difficulties that the beginning teachers face as they attempt to master the art of teaching. This could make learning uniform irrespective of whether an instruction is practiced by a novice or an expert teacher (Ball & Forzani, 2009), thus reducing the struggle usually faced by the novice teachers in their early years of teaching.

One of the common core practices and competencies, specifically in science teacher education is pedagogical content knowledge (PCK) (Aydeniz & Kirbulut, 2014). All science teachers, including those in training, are expected to develop their PCK of the subject matter, if their

teaching is to be effective. This study is therefore in line with this understanding, where developing the physical science PGCE pre-service teachers' (PPSTs) PCK at the topic level is considered important (Mavhunga& Rollnick, 2017). It is through this stand that the study investigated how the PPSTs translated the TSPCK (acquired in the context of planning to teach through engagement with a formal intervention) into the actual classroom teaching and the ultimate impact of their teaching on learner conceptual performance on the topic taught.

2.2. PCK as a knowledge base for Teachers

PCK is a useful theoretical framework that is commonly used in science education to investigate the teachers' knowledge and understanding of teaching. The concept of PCK was initially developed and introduced by Shulman who referred to it as a form of knowledge that connects a 'teacher's cognitive understanding of subject matter and the relationships between such understanding and the instruction teachers provide for learners (Shulman, 1986, p.25). Shulman referred to PCK as a unique province that distinguishes the teachers from the content specialists. It is therefore regarded as a valuable knowledge in enhancing effective teaching and learning of science in several ways. According to Loughran *et al.* (2012) "PCK begins to emerge because the manner in which the content is being developed, questioned, manipulated, and tested is the driving force for the way content and pedagogy are both shaped, and interact in practice" (p. 8). This is why a successful chemistry teacher is expected to have adequate content knowledge, including different ways of communicating their knowledge logically for accessibility to the learners (Tobin & McRobbie, 1999; Okanlawon, 2010; Miller, 2011). Furthermore, the teachers' PCK can also be defined by their ability to recognize the learning difficulties and misconceptions that the learners bring into the classroom (Van Driel *et al.,* 1998). The teachers' knowledge and appreciation of the learner difficulties and preconceptions influences their choice of instructional strategies and representations that work towards efficiently explaining the difficult concepts (Mthethwa-Kunene *et al.,* 2015). Therefore, if a chemistry teacher has different ways of teaching chemical reactions concepts, it may be easier for him/her to change an instructional strategy (using a different analogy/representation) in order to assist the learners who, have some difficulties understanding the lesson content (Magnusson *et al.,*1999). PCK is therefore argued to result from the transformation of various knowledge bases for teaching (Aydin & Boz, 2013). PCK and its knowledge components can provide researchers with avenue to describe effective teaching

practices and this may inform science teacher education programmes (Aydin *et al*., 2014). The development of PCK in teachers is therefore an important aspect in science teacher-education. It has however been argued that PCK develops over time as teachers teach particular subject matter (Chan & Yung, 2017; Cooper, Loughran & Berry, 2015; Loughran, *et al.*, 2012). This implies that, the development of a high-quality PCK is a continuing process which progresses through initial teacher education programmes and carries on through teaching practice and professional training (Adadan & Oner, 2014). With PCK regarded as a communication tool between the teacher and the learner in the classroom setting (Van Driel *et al.*,1998), it is important that PSTs are assisted to develop their PCK in the teacher training institutions to develop their competence to teach for understanding.

The significance of PCK taught in initial teacher training

There is an agreement among the researchers that PSTs enter the teaching programmes with naive cognitive demands that teaching will make of them (Nilsson & Loughran, 2012; Hume & Berry, 2011). PSTs have also been argued to have a lot of misconceptions and fragmented knowledge which affects their ability to create challenging learning situations (Tondeur *et al.*, 2012). Content knowledge is however, argued to be a pre-cursor for PCK as highlighted above (Cooper, *et al.*,2015), necessitating teachers to have a well-developed content knowledge of what they are expected to teach. Furthermore, Mavhunga (2014) revealed that even with an improved content and pedagogical knowledge, the PSTs lack competence to efficiently translate their own understanding to that of the learners. This suggests their low PCK level. It is, however, common understanding in the literature that PCK develops over time through practice, hence it is unlikely to find a developed PCK in PSTs (Chan & Yung, 2017). It becomes reasonable therefore to introduce PCK in the pre-service education programmes to train teachers who can develop meaningful lessons that are accessible to the learners (Kind, 2009). A concern in teacher education programmes then is to develop teachers with adequate content knowledge and the ability to teach it for understanding. With the understanding that a teacher is not just a teacher but an 'English teacher' or a 'chemistry teacher' (Geddis *et al.*, 1993, p. 675), it implies that the teacher preparation programmes should help PSTs develop the knowledge for teaching, with special emphasis placed on the quality of teaching a specific topic.

2.3. Multidimensional nature of PCK

Since the introduction of PCK by Shulman (1986 and 1987) as a special amalgam of the content knowledge and pedagogy, various researchers have suggested different conceptualizations of PCK, thus proposing different features to integrate in the conceptualization of PCK. One of the highly influential and mostly adapted conceptualizations is the one proposed by Magnusson et al. (1999) whose argument is that effective teaching requires the integration of knowledge from various domains. Magnusson et al. (1999) conceived PCK as consisting of five discrete components. These are: (a) orientations towards teaching science (which includes teachers' knowledge and beliefs about the purposes and goals for teaching science), (b) knowledge of the science curricular (which includes knowledge of which concepts to teach for specific topics at a particular grade level), (c) knowledge of instructional strategies (knowledge of specific instructional strategies and representations for teaching particular topics), (d) knowledge of assessment of scientific literacy (knowledge of which parts of student learning are the most important to assess in a certain content area to ascertain the learners' understanding of science concepts) and (e) knowledge of the learners' understanding of science (which includes knowledge about concepts that might be difficult for the learners to understand, as well as their misconceptions).

The three components of PCK (orientations, assessment, and instructional strategies) identified by Magnusson et al. (1999) are generic and not specific to any topic, whilst the inclusion of (science curricular knowledge and learners' understanding of science) encompasses the topic specific nature of PCK. It is important to note at this point that a well-developed PCK is not reflected in only the knowledge of different knowledge components, but it also comprises the interplay of the different types of knowledge (Aydin *et al.,* 2014; Van Driel & Henze, 2012). "Apart from the extent of the respective components, the strength of the interconnections is an indicator of the quality of a teacher's personal pedagogical constructions" (Henze & Barendsen (2019, p. 206). While the Magnusson et al.'s (1999) model provides multiple components of PCK, it does not relate the different components to each other (Henze & Barendsen, 2019).

Furthermore, in their study on pedagogical content knowledge taxonomies, Veal and MaKinster (1999) identified three general taxonomies of PCK. They argued that these taxonomies could be

used to generally describe the skills that need to be developed by teachers of all kinds. Thus, they are not for specific subjects or content areas, hence they can be employed across various content areas. The three taxonomies identified by Veal and MaKinster are: (i) general PCK (specific to the disciplines of science, art, history, math, or English), (ii) domain-specific PCK (which focuses on a single domain within a specific discipline of interest) such as chemistry, biology, or physics and (iii) topic-specific PCK (where the focus is on the individual topics within the domains of science) (Veal & MaKinster, 1999, p. 6). In line with the topic specific nature of PCK, proposed by Veal and MaKinster (1999) are studies by Geddis et al. (1993) as well Mavhunga and Rollnick (2013), who identify five components of the pedagogical transformation of content knowledge. These are: the learners' prior knowledge including misconceptions, curricular saliency, what makes a topic easy or difficult to understand, representations including analogies, and conceptual teaching strategies. Mavhunga and Rollnick (2013) refer to these points as different kinds of knowledge needed for the transformation of the subject matter. Similar to this is McLaughlin's (2006) perception of PCK. Accordingly, PCK is said to include "an understanding of students' misconceptions and difficulties with particular concepts, exemplars and analogies that help students to understand the concepts, specific instructional strategies such as questions that help students to link ideas between the concepts and assessment methods appropriate to the concepts" (McLaughlin, 2006, p. 8). Consequently, PCK is dependent on the knowledge of the components used by the teacher, including the ability of the teacher to interactively use those components in their teaching (Park & Chen, 2012). Therefore, PCK is not merely about the amount of knowledge in a number of component categories but also the quality of that knowledge and how it is put into action (Abell, 2008). In particular, the topic-specificity of PCK can be evaluated by looking at how the components of knowledge transformations are used together interactively to improve the learner comprehension of concepts. This could include the ability of the teacher to use multiple representations to address learner misconceptions or learner difficulties, making explicit through representations, what is important for students to learn. "PCK referring as it does to specific topics is distinct from the general knowledge of pedagogy, educational purposes, and learner characteristics. Moreover, because PCK is concerned with the *teaching* of specific topics, it may differ considerably from the subject matter knowledge of these topics," (De Jong, Van Driel & Verloop, 2005, p. 1).

While, without a doubt, PCK has been considered as a fruitful framework for exploring teacher knowledge, "research about and application of PCK had been suffering from a lack of shared definitions and conceptualizations of the construct in the field" (Carlson, Stokes, Helms, Gess-Newsome, & Gardner, 2015, p. 28), making it difficult to highlight what knowledge components specifically constitute PCK without any uncertainty. The focus on developing the PPSTs' PCK as part of their professional knowledge, however, remains indispensable (Evens, Elen, Larmuseau & Depaepe, 2018), which fuels the need to address PCK without ambiguity by demonstrating a sound understanding of the constituent knowledge components which must be emphasized to the PPSTs in the course of introducing a construct of PCK of them.

2.4. PCK studies with PGCE pre-service teachers

PCK has been investigated through a variety of approaches. Some researchers have studied the PCK of PGCE science student teachers (de Jong *et al.*, 2005; Findlay & Bryce, 2012). Loughran, Mulhall & Berry (2004, p.372) observe that "Research often involved: exploration of what teachers do and know about some aspect of teaching a particular topic and might often include comparisons of teacher knowledge between different teachers, between novice and expert teachers or as a result of some kind of intervention".

One study was conducted by Halim and Meerah (2002) who examined Malaysian science trainee teachers' PCK of selected physics concepts. This included the teachers' knowledge of the learners' understanding of conceptions and misconceptions as well as the teachers' knowledge of instructional strategies and representations appropriate for teaching specific topics. Halim and Meerah investigated a cohort of 12 student teachers registered in a one-year postgraduate training course from various science subjects. The study found that the trainee teachers' ability to transform knowledge for learner accessibility was limited which is indicative of their low PCK level for teaching those concepts. The findings showed that the student teachers' knowledge of those components of PCK depended on their understanding of the content knowledge. They found that the trainee teachers had problems in understanding the scientific ideas which reflects their low level of content knowledge. They therefore argued that the trainee teachers' minimal content knowledge had a negative impact on their ability to identify learner misconceptions and to choose the strategies and representations appropriate for teaching and explaining difficult concepts

effectively. Similarly, a study by de Jong et al. (2005) investigated the PSTs' PCK of using particle models in teaching chemistry in Netherlands.The study was based on the pre-service post-graduate chemistry teachers' teaching at the secondary school level. The study revealed that at the end of the programme, the teachers had developed PCK on the use of particle models in the teaching of chemistry through learning and teaching. They also argued, however, that the development of PCK varied for different pre-service teachers. Likewise, Findlay and Bryce (2012) (in the United Kingdom) engaged in a longitudinal study for four and a half years, following a group of beginning physics teachers enrolled in a one-year Professional Graduate Diploma in Education (PGDE) course to explore their PCK development of teaching basic electricity. They interviewed fifteen student teachers within the PGDE year and later followed six of them into their teaching as newly qualified teachers in their first year of teaching and two and a half years later into the field. They identified two occurrences in their results: that at the beginning of their profession as newly qualified teachers, the teachers focused on how they could transform their content knowledge for accessibility by the learners; the transformation changed with the teachers' experience in practice as they also learnt to interact with the learners when teaching. The interaction indicated their PCK development. McNicholl, Childs and Burn (2013) also focused their United Kingdom study on the ways in which the PGCE science teachers developed their PCK. Their study specifically focused on the factors that facilitated the teachers' PCK development. They found that teachers drew their knowledge and understanding from their more knowledgeable colleagues (specialist-teachers) whenever they encountered some difficulties. This involved assistance with the subject content or the teaching strategies and resources to use. McNicholl and colleagues argued that, even though they were confident that these teachers survived their first teaching encounter and developed their PCK through the help of the specialist teachers, this was not an assurance that all PGCE practicing students experience the same treatment and help. Their argument was that not all the schools have specialist teachers and that in some schools there might be no collaboration between teachers within a department, thus making it difficult for student teachers to acquire knowledge from such teachers. It is for such reasons that equipping the PPSTs with core practices of expert teachers such as the development of their PCK in teacher training is important. It helps them to engage in sound teaching from the beginning of their career.

2.5. Theoretical framework

This study employed the PCK theoretical framework that describes the teacher knowledge for teaching science and its link to learner outcomes. The exploration of this framework was informed by the Refined Consensus Model (RCM) of PCK, including the TSPCK construct. The RCM Model of PCK was intended to "provide researchers with a means to situate studies of student science learning in relationship to PCK by focusing on teachers and classrooms. Another aim was to provide science teacher educators [with the] means to situate theories about the development of teacher PCK through formal education, in-service professional learning, and firsthand teaching experiences" (Carlson & Daehler, 2019, p. 79). The model is presented in Figure 2.1.

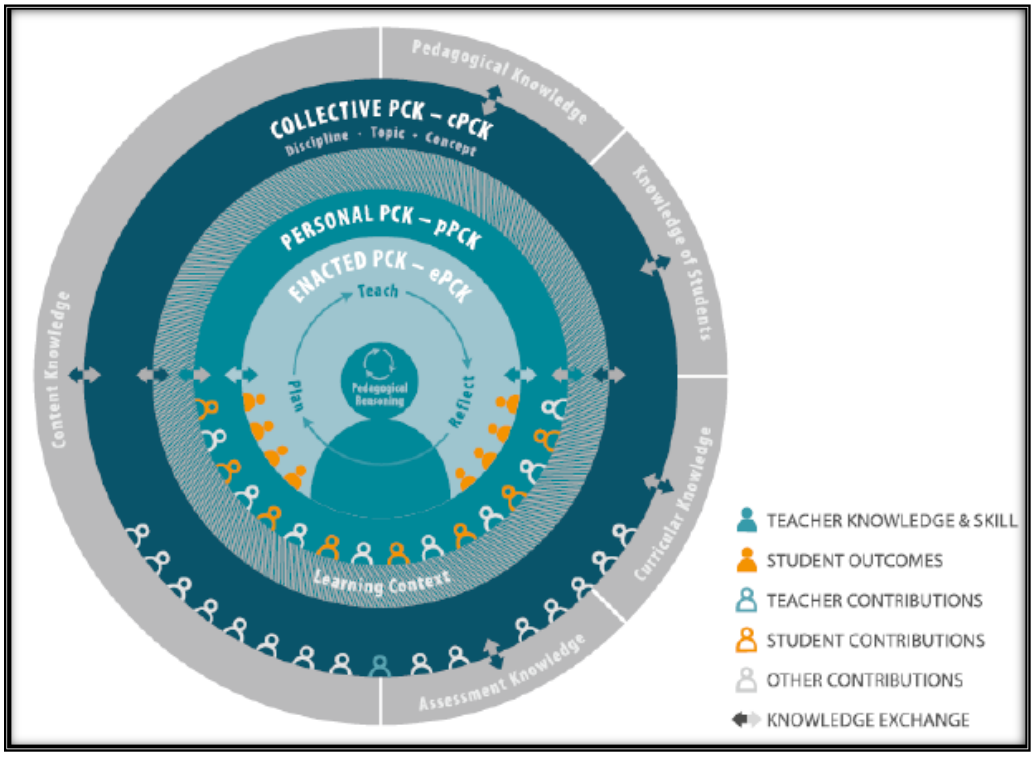


Figure 2. 1: Refined Consensus Model of PCK (Carlson & Daehler, 2019, p. 83)

The concentric model enables the refinement of the nuances and relationships among different types of PCK, placing teachers and learners at the center to elevate the value of pedagogical reasoning, including the dynamic nature of enacted PCK (ePCK). By doing so, the RCM represents the multi-dimensions of PCK, its projected development in teachers and influence on what the teacher does and the ensuing impact of that action on the learners' conceptual knowledge. Thus, the model demonstrates the complex layers of knowledge and experiences that shape and inform science teachers' practice and facilitate student outcomes. The model identifies three distinct

realms of Pocketless are: *Collective PCK (cPCK), personal PCK (pPCK)* and *enacted PCK (ePCK*) (Carlson & Daehler, 2019).

The first realm, collective PCK (cPCK) refers to PCK acquired in formal courses where published knowledge about PCK is discussed. cPCK is the specialized knowledge shared by the teacher community and is acquired through formal courses such as the initial teacher development programmes where published knowledge is discussed (Carlson & Daehler, 2019). The second realm is the personal PCK (pPCK). In teacher training programmes, the courses that expose PSTs to PCK development teaches them cPCK and each individual PST personalizes that PCK forming their pPCK. The teachers' pPCK which is observed when planning to teach is referred to as plPCK (Mavhunga& van der Merwe, 2020) while that observed in classroom enactment is referred to as ePCK (Carlson & Daehler, 2019). The three realms, cPCK-plPCK-ePCK, can thus be examined to determine the teachers' PCK development and are influenced by filters and amplifiers such as teacher beliefs and attitudes towards science (Mavhunga& van der Merwe, 2020). Although portrayed only under the cPCK realm on the model in Figure 2.1, all the three realms of PCK exist in three different grain sizes. Accordingly, the PCK-RCM model reflects the discipline, topic and concept-specific PCK as the grain sizes in a continuum found in each of the three realms of PCK (Carlson & Daehler 2019).

Using Geddis et al. (1993)'s notion of PCK as topic specific, Veal and MaKinster (1999) referred to this as "the most specific and novel level of the general taxonomy" (p. 6). Some researchers have been interested in the idea that development of the teachers' PCK begins at the topic level. The argument is that PCK is accessed most usefully when teaching within the topics of a discipline (Abell, 2008). This kind of PCK was referred to by Mavhunga and Rollnick (2013) as topic specific (TSPCK) and defined as the knowledge needed to transform content knowledge of a specific topic in science. As observed in the RCM of PCK, the topic specific nature of PCK has been recognized as one of the grain sizes of PCK. Five content-related knowledge components of TSPCK have been identified as topic specific components of TSPCK that distinguish it from other grain sizes of PCK (e. g. Geddis *et al.,* 1993; Mavhunga & Rollnick, 2013). They are: (i) learners' prior knowledge including misconceptions, (ii) curricular saliency, (iii) what makes a topic easy or difficult to understand, (iv) representations, including analogies, and (v) conceptual teaching strategies. The following is a brief description of the five TSPCK components.

i) **Learner prior knowledge:** This component comprises learner preconceptions, misconceptions, and alternative conceptions about a topic. Consideration of learner prior knowledge assists with the elimination of ambiguity associated with a concept and in making connections among the concepts (Amelia, Handayanto & Muhardjito, 2016). Knowledge of these could contribute to the development of teaching strategies that are cognizant of such misconceptions by creating conceptual bridges between what is familiar and what is new.

ii) **Curricular saliency:** It involves knowing the most important and core concepts of the topic, what is peripheral, immediate/pre-concepts and the logical sequencing of the concepts (Mavhunga, 2016). It refers to the learning of various topics as positioned in the curriculum. It is through the understanding of this that teachers can judge the depth to which the topic should be covered and the amount of time to spend teaching it (Geddis & Wood, 1997; Shulman, 1987).

iii) **What is difficult to teach or understand:** This constitutes concepts that are not easily understood by the learners and require critical emphasis and attention from teachers. It comprises understanding of gate keeping concepts within the topic that contribute to the difficult nature of the topic, also making it difficult for teachers to teach them (Huddle, White, & Rogers, 2000; Quilez-Pardo, 1995).

iv) **Representations:** This component refers to the teachers' understanding of a range of subject matter representations that include illustrations, analogies, models, and simulations to be used in the teaching of a specific topic/concept. Chemistry teachers, in particular, make use of sub-micro, macro and symbolic levels of representations to explain concepts. The understanding and use of these representations by the teachers facilitate the learner conceptual understanding by helping learners to make sense of the concepts under discussion (Mitchell, Charalambous & Hill, 2014).

v) **Conceptual teaching strategies:** This component comprises the use of effective instructional strategies, including multiple levels of representations, for particular misconceptions, known areas of difficulty or important concepts, by emphasizing what must be understood (Mavhunga & Rollnick, 2013). It involves pulling together thoughts from all the other four TSPCK components to explain a concept in a way that makes it accessible and comprehensible to the learners.

The components are content-specific, because of their specific requirement to focus on the subject matter knowledge. The interactions of the five content-specific knowledge components demonstrate the quality of PCK in a given topic (Park & Chen 2012). This study has a special focus on the topic specific grain of PCK. The study adopted the simplified model proposed by Mavhunga and van der Merwe (2020) that positions the topic specific PCK (TSPCK) in the RCM of PCK. Figure 2.2 presents the simplified model.

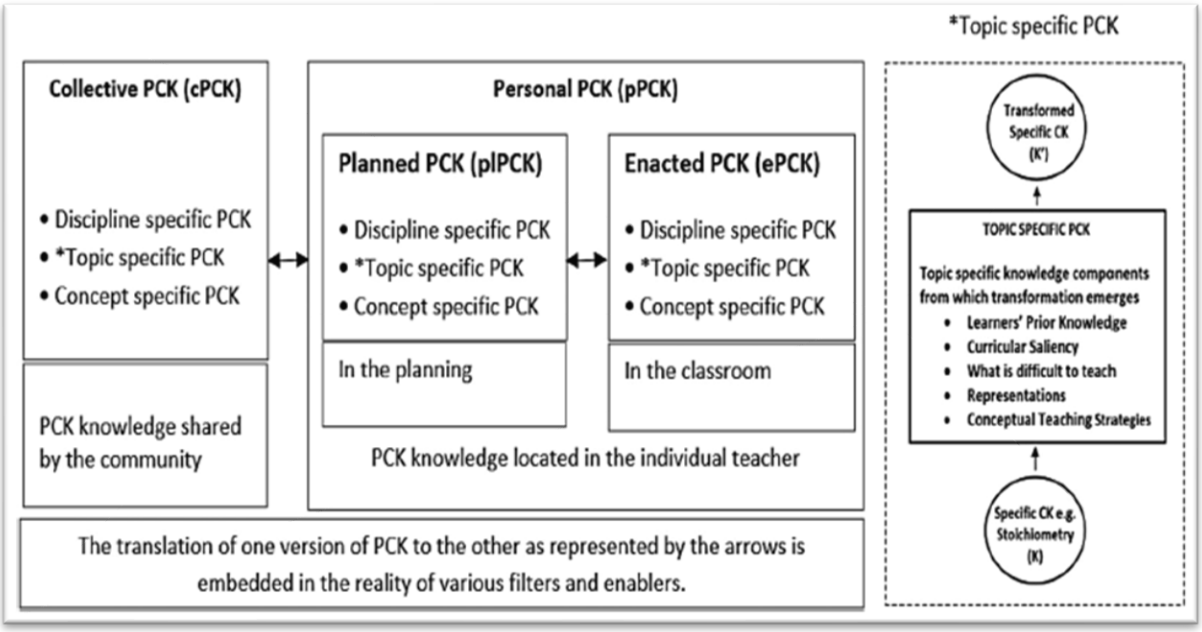


Figure 2. 2: Simplified positioning of TSPCK in the refined consensus model of PCK (Mavhunga and van der Merwe, 2020)

The concentric RCM model of PCK uses pPCK to represent the personal PCK (as the Mavhunga& van der Merwe model does). The major difference between the two models is that the RCM model presents enactment (ePCK) as the major manifestation of the personal PCK (pPCK) whereas the Mavhunga and van der Merwe's (2020) model presents the planning (plPCK) and enactment (ePCK) as equally important manifestations of the personal PCK (pPCK).

What makes TSPCK fit into the RCM of PCK includes the fact that the model places PCK at a topic specific level which differentiates it from the generic discipline based PCK. This is in line with the consensus assertion among the science education researchers that defined PCK "as both a knowledge base used in planning for and the delivery of topic-specific instruction in a very specific classroom context" (Gess-Newsome, 2015, p. 42). The TSPCK model also identified 5

content-specific knowledge components that can be used in the pedagogical transformation of content knowledge for any topic under investigation. Finally, there are empirical findings which affirm that TSPCK can be taught to PSTs to develop planned TSPCK (plTSPCK) (Mavhunga & van der Merwe, 2020; Akinyemi, 2020). Because this study focuses on the topic specific grain of PCK acquired through collective PCK, I track how the plPCK translated into ePCK (referred in this study as plTSPCK and eTSPCK) and its ultimate influence on learner outcomes.

The argument under TSPCK is that 'when a particular element of content knowledge is thought about and reasoned through the five content-specific components, understanding for teaching is generated that is specific to that topic' (Mavhunga & Rollnick 2013, p.33). That is, if the teacher's content knowledge of one chemistry topic (e.g., chemical bonding) is transformed using those five content-specific components, the same process will have to be repeated for the other topics (Mavhunga& Rollnick 2013). Accordingly, teachers must familiarize themselves with different ways in which any topic can be presented, how to introduce it, the demonstrations required for further clarifications, the questions to ask, how to respond to the learners' questions, the laboratory activities to be employed and adopted in teaching the topic as well as how the subject matter can be applied in the outside world (Aydin, Friedrichsen, Boz & Hanuscin, 2014). According to Aydin et al. (2014), "while examining teachers' PCK for teaching a single topic provides valuable information, focusing on the same teachers' PCK for different topics in the same discipline will help researchers better understand the nature of PCK" (p. 658).Therefore, the competence gained to transform their content knowledge for each topic, and an improvement in the teacher's TSPCK on various topics has the capacity to influence the teacher's general PCK at the discipline/domain level.

2.6. PCK quality through an interplay of knowledge components

While there is a common understanding in the PCK literature that PCK can be examined by looking at teachers' firm understanding of various knowledge components (Magnusson *et al*., 1999), there is also an understanding of the need for development of competence to efficiently integrate those components in a coherent way (Aydin *et al.,* 2015; Park & Chen, 2012). Thus, a well-developed PCK is best explained through looking at the interactions among knowledge components. Grossman (1990) was the first researcher to consider the interaction among knowledge components and reported that "these components are less distinct in practice than in theory" (p. 9).

This point was emphasized further by Cochran et al. (1991) who argued that PCK components are so integrated and interrelated that they cannot be considered as separate knowledge bases. Fernández-Balboa and Stiehl (1995) adopted the same idea of knowledge integration and reported that "it is not the separate existence, but rather the intersection and rightful integration of all these PCK components that comprises good teaching" (p. 294). Focused on classroom teaching of Solar systems and the Universe, a study by Henze, Van Driel and Verloop (2008) explored teachers' integration of various knowledge components of PCK, based on two different kinds of science orientation which relate knowledge of assessment, knowledge of learner and instructional strategies. Their findings revealed that teachers' knowledge of the learners interacted strongly with instructional strategies employed. Similar to this was Park and Oliver's (2008) findings that the teachers' development of knowledge of the learner (including misconceptions) shaped their knowledge of teaching strategies and assessment. Using a quantitative approach to explore the intra-relationships between pre-service science teachers' PCK components on a topic of ozone layer depletion, Kaya (2009) found a moderate relationship to exist among PCK components. Similarly, while focused on university lecturers of quantum chemistry, Padilla and Van Driel (2011) found a strong link between their orientation and knowledge of instructional strategy, curricular knowledge and knowledge of the learners. Using a different quantitative approach, Park and Chen (2012) mapped out interactions of biology teachers' PCK demonstrated in the classroom teaching of photosynthesis and heredity. The authors found an idiosyncratic kind of interaction among the knowledge components which were specific to the topic (i.e., knowledge of learner and instructional strategy) (Park & Chen, 2012). Aydin and Boz (2013) used Park and Chen's (2012) method of mapping out and enumerating PCK components, to examine two chemistry teachers' PCK components interactions in teaching redox reactions and electrochemical cells. Using a scoring rubric, Aydina and Boz were able to project the quality of the interactions, including how they facilitated the learners' learning. Similar to Park and Chen (2012), they found knowledge of the learners and instructional strategy (which are topic specific) to be central in the integration (Aydin & Boz, 2013). Furthermore, Aydin et al. (2014) also examined the nature of teachers' PCK in teaching electrochemical cells and nuclear reactions. They found that although their PCK looked similar, the difference was observed in the interacting knowledge components which shaped the observed PCK.

While science teacher educators agree that coherent and integrated PCK is the key to effective teaching (Abell, 2008; Park & Oliver, 2008), it remains a concern that pre-service teachers have fragmented PCK (Lee, Brown, Luft, & Roehrig, 2007). However, researchers also agree on the importance of helping PSTs to develop the ability and understanding of how to coherently integrate the components of PCK for effective learning outcomes (Aydin & Boz, 2013; Park & Chen, 2012). An example of studies that aimed to investigate this issue is Kaya (2009) who reported a moderate correlation for intra-relationship among the knowledge components, including a low relationship between other knowledge components and the PSTs' knowledge of assessment. Using Magnusson et al.'s (1999) model of PCK, Aydin et al. (2015) examined the nature of interactions among the PCK components demonstrated by a group of PSTs during a practicum course on a chemistry topic of the rate of reaction. The findings revealed an idiosyncratic nature of integrations among the knowledge components. The authors also found that the development of PSTs' PCK grew remarkable from fragmented to a more integrated and coherent one at the end of the course (Aydin *et al*., 2015). Likewise, focusing her study on PSTs' TSPCK development, Mavhunga (2018) examined how the content-specific components of PCK interact when planning to teach a topic of chemical equilibrium. Using an in-depth qualitative method, Mavhunga identified moments of interactive use of two or more knowledge components, referred to as the TSPCK episodes similar to PCK episodes in Park and Chen's (2012). The study revealed that the components of PCK in a topic interact among each other in linear, interwoven, or a combination of the two structures. Mavhunga (2018) also observed sophisticated component interactions emerging from PSTs' lesson plans and explanations on content representation (CoRe) prompts.

2.7. Capturing and measuring the quality of PCK

PCK is an elusive and internal construct which teachers find difficult to articulate (Mazibe, Coetzee & Gaigher, 2020; Kagan, 1990). Capturing and measuring the quality of PCK and its associate TSPCK therefore remains a challenge. Various techniques and methodologies are reported to have been used in the literature, with the aim of capturing the teachers' thought processes about teaching in order to measure the quality of their PCK. For example, data has been collected through classroom observations, written reflections, lesson plans, interviews and written depictions of PCK (Friedrichsen *et al.,* 2009; Nilsson, 2008; Park & Oliver, 2008b; van Driel *et al*., 2014). Content Representations (CoRes) and Pedagogical and Professional Experience

Repertoires (PaP-eRs) were both developed by Loughran et al. (2004) to capture teachers' thinking and reasoning about teaching. The development of CoRes requires teachers to identify the big ideas within each topic and to expand on the teaching of each, as guided by specific prompts. PaP-eRs, which are specific accounts of practice, provide an understanding on "the decisions underpinning the teacher's actions" (Loughran *et al.*, 2004, p. 377). The two tools provide qualitative reflections and understanding into the teacher's planning of a lesson (Loughran *et al.*, 2004). The research community, however, has taken up the use of CoRes, more than the PaP-eRs (Cooper *et al.*,2015), especially in pre-service science teacher education (Hume & Berry, 2011, 2013; Nilsson & Loughran, 2012). A CoRe tool has been a useful instrument in capturing and assessing teachers' and pre-service teachers' PCK (Chordnork & Yuenyong, 2014) which includes tracking the development of PCK before, during and after an intervention (Nilsson & Loughran, 2012; Rollnick & Mavhunga, 2016). Accordingly, these tools can assist pre-service or novice science teachers to develop the foundations of PCK that can be enhanced through experience and reflection upon practice (Hume & Berry, 2011; Aydeniz & Kirbulut, 2014). Several studies that have used CoRes to develop and enhance PSTs' PCK have reported positive outcomes (Hume & Berry, 2013; Loughran, Mulhall, & Berry, 2008). For example, a study by Loughran et al. (2008) used CoRes and PaP-eRs to frame PST's thinking about the connection between science content and pedagogy. These authors found that PSTs developed more sophisticated views about learning to teach science, including how to teach for understanding. Similarly, a study by Bertram and Loughran (2014) had the PSTs complete CoRes to use during their teaching experience. They reported the PSTs' improved knowledge for teaching, resulting from the use of those CoRes in their teaching (Bertram & Loughran, 2014). Furthermore, Qhobela and Moru (2014) worked with a group of Physics teachers whose teaching was dominated by a chalk and talk traditional teaching strategy. The participants were introduced to CoRe as a tool to assist them with analyzing the content and pedagogy of a topic by guiding them to design and implement lessons that support the learners' construction of new knowledge. Qhobela and Moru reported an improvement in the participants' teaching processes following this intervention.

Generally, CoRes have been used to portray holistic overviews of teachers' PCK related to the teaching of a particular topic (Williams, Eames, Hume & Lockley, 2012; Hume & Berry, 2013); hence they can be considered as the best technique to use to elicit and to record PCK directly from the teachers (Kind, 2009). Both CoRes and PaPeRs are qualitative in nature, hence their use

provides an insight into the quality of PCK at a descriptive level. This makes them more appropriate for capturing than for measuring teachers' PCK in a specific topic (Mavhunga & Rollnick, 2014).

Other methods used in capturing PCK include the video recording of lessons followed by scoring with a specially designed rubric (Park & Chen, 2012) or stimulated recall interviews on lessons taught (Bishop & Denley, 2007; Smith & Banilower, 2015). For example, Park, Jang, Chen and Jung (2011) used a PCK rubric designed by Park, Chen and Jang (2008) in order to measure teachers' levels of PCK. The rubric was theoretically grounded in the pentagon model of PCK, which defined PCK as one of the five integrated knowledge components (Park & Oliver, 2008). The rubric focused on measuring: i) the teachers' knowledge of student understanding of the subject matter and ii) their knowledge of instructional strategies and representations among the five knowledge components (Park *et al*., 2008). More studies that used PCK tools include: Carpendale and Hume (2019) in Physics, Aydeniz and Kirbulut (2014) in chemistry and Jüttner, Boone, Park and Neuhaus (2013) in Biology. They all described PCK at a discipline taxonomy level (Veal & MaKinster, 1999). Such models are thus considered epistemologically unsuitable for measuring teachers' PCK at a topic specific level.

Using a topic specific PCK realm (TSPCK), Mavhunga and Rollnick (2013) developed a TSPCK research tool (see Appendix A) used to capture the PSTs' knowledge for teaching a topic of chemical equilibrium by taking into consideration, the five content-specific knowledge components. The TSPCK tool requires qualitative explanations that demonstrate teachers' understanding of a particular TSPCK knowledge component. Furthermore, it gives an opportunity to gain insights into teachers' understanding of the interactive use of other knowledge components from the portrayed explanation. Alongside the TSPCK tool was a 4-criterion planned TSPCK rubric (see Appendix A) that categorized the TSPCK captured into different levels of quality (Mavhunga & Rollnick, 2013). The rubric criteria emphasize varying extents of interactive usage of TSPCK components (Mavhunga & Rollnick, 2013), hence allowing for the teachers' TSPCK to be categorized at different levels. The four different levels are: Limited (1), Basic (2), Developing (3) and Exemplary (4), with the Developing and Exemplary levels representing the higher levels of quality plTSPCK. The categories can be described qualitatively while also allowing for the quality of TSPCK to be measured quantitatively. Interestingly, the TSPCK tool

and the corresponding rubric are appropriate and epistemologically suitable for capturing the quality of PCK in each topic, as guided by the TSPCK construct. Following the same understanding, more TSPCK tools were developed in different topics such as organic chemistry (Davidowitz & Vokwana, 2014), chemical bonding (Toerien, 2017) and particulate nature of matter (Pitjeng-Mosabala & Rollnick, 2018). Recently, Miheso (2018) developed and validated a 3-criterion enacted TSPCK rubric that captures the teachers' PCK portrayed in their classroom teaching (see Appendix G). The rubric categorizes the quality of teachers' eTSPCK into simple, proficient or sophisticated levels, based on the extent of interactive use of knowledge components identified as TSPCK episodes from the teachers' classroom explanations (Miheso, 2018). On the rubric, the proficient and sophisticated TSPCK episodes represent higher categories of quality eTSPCK. Attempting to capture and measure the PPSTs' plTSPCK, this study adopted a validated TSPCK tool with its rubric designed by Mavhunga and Rollnick (2013) on a topic of Chemical Equilibrium and CoRes (Loughran *et al*., 2012) for capturing their thought processes about teaching Chemical Equilibrium. Similarly, the enacted TSPCK rubric (Miheso, 2018) was adopted to portray the quality of PPSTs' eTSPCK on their actual teaching of Chemical Equilibrium. Using the adopted tools and rubrics presented above, this study was able to capture and measure the quality of PPSTs' plTSPCK and eTSPCK in a topic of Chemical Equilibrium.

2.8. Understanding the cPCK-plPCK-ePCK trajectory link to learner outcomes

2.8.1. The cPCK-plPCK-ePCK trajectory

According to Shulman, (1987), the process that results in effective teaching of content in the classroom begins way before the actual act of teaching itself. It begins with a thorough pedagogical reasoning of the content. The argument made by Shulman is that PCK is embedded in the actions of teachers "from being able to comprehend subject matter for themselves, to becoming able to expose subject matter in new ways, reorganize and partition it, clothe it in activities and emotions, in metaphors and exercises, and in examples and demonstrations, so that it can be understood by students" (Shulman, 1987, p. 13). This implies that PCK can be explored in both planning as plPCK and in the actual classroom enactment as ePCK. This coincides with Baxter and Lederman's (1999) line of thought, that PCK goes beyond what a teacher knows but extends to "what a teacher does" in the classroom and to the reasons for the types of actions that he/she takes

in relation to teaching a specific topic (p. 158). Accordingly, because of the tacit nature of PCK (Aydeniz & Kirbulut, 2014; Baxter & Lederman, 1999), it is best to explain it by looking at not only what teachers know about teaching a topic (usually observed in their planning for teaching) but also their classroom enactment, including when teachers reflect on their teaching (Magnusson *et al.,* 1999; Carlson & Daehler 2019).In the same line of thought is the definition of PCK portrayed in the Consensus Model (CM) where PCK is referred to as "both a knowledge base used in planning for and the delivery of topic-specific instruction in a very specific classroom context, *and* as a skill when involved in the act of teaching" (Gess-Newsome, 2015, p. 30-31). This stamps the argument that a teacher's personal PCK should be explained at both planning and enactment levels.

It is however important to note that just because a teacher knows what to do and demonstrates a developing PCK does not guarantee an automatic translation of that knowledge into classroom enactment (Gess-Newsome, 2015; Aydeniz & Kirbulut 2014), due to the complexity of classroom teaching. It is only when that knowledge is enacted in the actual classroom teaching that it can be called ePCK, and eTSPCK when considered for a specific topic. According to Ball et al. (2008), it is through an understanding of PCK manifestations at both planned and enacted levels that "the relationships among teacher knowledge, teaching, and student learning" (p. 390) can be explored and understood. While plPCK and ePCK cannot be fully separated (Abell, 2008) since they both represent a teacher's pPCK, acknowledging each realm of PCK provides richer insights into understanding PCK development and subsequently its manifestation in the actual classroom teaching. In other words, while plPCK is the kind of knowledge evident when planning to teach, ePCK comprises the knowledge demonstrated by the teacher when teaching in the actual classroom in response to the learners' learning needs (Aydeniz & Kirbulut, 2014; Park & Oliver, 2008). Understanding how the pPCK manifests in both planning and enactment is necessary for effective teaching and learning of the subject matter.

Furthermore, PCK is regarded as a communication tool between the teacher and the learner in the classroom setting (Van Driel *et al.*,1998). There is, however, a general understanding that PCK develops through experience as teachers engage in their teaching of subject matter (Chan & Yung, 2017; Aydin & Boz, 2013). This knowledge is believed to grow continuously as teachers engage in planning, carry out and reflecting on teaching and learning (Nilsson & Loughran, 2012). In view of that, the novice and pre-service teachers (PSTs) have a less developed PCK which calls for the

need to support and grow their PCK (Aydin *et al.,* 2015). Initial teacher education programmes are therefore obliged to help the PSTs' to develop PCK (Aydeniz & Kirbulut, 2014) with the purpose of "ensuring that individuals enter the teaching profession with more classroom experience and deeper knowledge" (Aydin *et al.,* 2015, p. 37). The concerning issue however has always been about the transferability of PCK (plPCK) into the actual classroom teaching learned (Gess-Newsome, 2015), following an exposure to collective PCK (cPCK) and by its association cTSPCK. As argued by Mavhunga (2014), TSPCK itself is not transferrable. It is the application of the learnt competence to effectively use the 5-content specific TSPCK components to transform the content of a new topic that is transferrable. Mavhunga referred to this skill as pedagogical transformation competence (PTC). For example, Akinyemi (2020) followed a group of PSTs who were exposed to the TSPCK construct in the form of an intervention, to determine the transfer of learnt competence into classroom practice. Akinyemi reported an improvement and similar quality of TSPCK revealed in planning (plTSPCK) and in the PSTs actual teaching of the same topic of intervention (eTSPCK). Likewise, a study by Mazibe et al. (2020) studied physics teachers' PCK, displayed when developing content representations (CoRes) tool and during interviews as well as that demonstrated in their actual classroom when teaching graphs and motion. Contrary to Akinyemi's findings, the authors indicated that the reported PCK (in the CoRes) and enacted PCK were not at the same level of quality (Mazibe *et al.,* 2020). Furthermore, it has been observed that most of the previous studies focused on either a single PCK realm (Park & Chen, 2012) or two realms according to Mavhunga and Rollnick (2013) who examined the cPCK-plPCK and Alonzo et al. (2019) who examined the pPCK-ePCK link as well as a recent study by Akinyemi (2020) who focused on the three realms, cPCK-pPCK-ePCK link to the learner outcomes. A study by Akinyemi (2020) contributed towards addressing the gap that existed for years in the literature on the link between the teachers' PCK and learner outcomes (Carlson & Daehler, 2019).

While little is known about how PGCE pre-service teachers develop their PCK, this study is aimed at contributing towards addressing this gap by exploring the development of their TSPCK through the cPCK-plPCK-ePCK continuum and ultimate link to learner outcomes. The significance of exploring TSPCK this way lay in the fact that very few studies have explored the entire continuum in a single study, particularly with PPSTs whose exposure to PCK and other pedagogies is limited to a single year as opposed to the 4-year period common to traditional pre-service teachers. Thus,

this study, reports comprehensively on the PPSTs' multiple dimensions of TSPCK captured as they move from the one PCK realm into another and the ultimate impact on learner outcomes.

2.8.2. Teacher PCK and learner outcomes

This study was guided by two important conceptualizations in the PCK literature. These included: (i) the Shulman's (1987) argument that "comprehended ideas must be transformed in some manner if they are to be taught" (p. 16) and (ii) the understanding that the value of 'pedagogically transformed content understanding' lies in its ability to positively influence the learners' understanding and conceptual performances (Rollnick &Mavhunga, 2015). The expectation in research is that a high-quality teaching should result in increased students learning (Mansor, Halim & Osman, 2010; Gess-Newsome, Taylor, Carlson, Gardner, Wilson & Stuhlsatz, 2019). In order to facilitate the learners' understanding, teachers must have a well-developed knowledge base for teaching, referred to by Shulman as PCK. The understanding is that with a well-developed PCK, teachers can make disciplinary ideas comprehensible for the learners (Cooper *et al*., 2015; Richardson, Byrne & Liang, 2018). Additionally, Mthethwa-Kunene et al. (2015) argued that the teachers' knowledge and appreciation of learner difficulties and preconceptions in their teaching may influence their choice of instructional strategies and representations that work towards efficiently explaining the difficult concepts. It is therefore important that a teacher knows how to teach the subject matter, including what to do when learners encounter some learning difficulties. This ability to connect the learners' knowledge and experiences in ways that make the content meaningful is the key to PCK, hence the assumption that teachers with sound PCK have the potential to effectively impact on the learners' outcomes.

Despite the argument in research that PCK should promote conceptual understanding, it has remained difficult to directly link teacher knowledge to learner outcomes in the sciences (Cross & Lepareur, 2015; Mansor *et al.,* 2010). This difficulty is associated with a multitude of factors, including teachers and students' beliefs which either filter or amplify the effect that teaching has on learner outcomes (Gess-Newsome, 2015; Carlson & Daehler 2019). Additionally, the learners' interest and readiness to learn, teacher education background, teachers' content knowledge, pedagogical content knowledge and pedagogical knowledge are also considered as the factors that contribute to the complexity of the classroom and learning (Blömeke *et al*., 2016; Gustafsson & Nilsen, 2016). Even so, the theoretical models of instructional quality consider teachers'

professional knowledge, more specifically PCK, as a factor which influences the quality of instructions and hence, the learner outcomes (Helmke, 2014; Kunter, Klusmann, Baumert, Richter, Voss & Hachfeld, 2013). Consequently, with PCK viewed as the central component of teacher development of knowledge for effective teaching (Park & Oliver, 2008), a highly developed PCK has the potential to yield a high-quality instruction (Richardson *et al.*, 2018) which may, in turn, result in the learners' higher achievement (Förtsch, Werner, Von-Kotzebue & Neuhaus, 2016).Some studies have been conducted in science education to show that PCK is one influential factor which contributes to learning and to learner outcomes (Alonzo *et al*., 2012; Förtsch *et al*., 2016; Keller *et al*., 2017; Akinyemi, 2020).

Multiple studies focused on schools in Germany have been conducted to determine the existence of a link between the teachers' PCK and learner outcomes. For example, Lange, Kleickmann and Moller (2011) explored elementary teachers' PCK and student achievement in science classrooms with the focus on the states of matter and changes of state. Alonzo et al. (2012) investigated the link between two German physics teachers' PCK and students' learning on a topic of optics. Similarly, Keller et al. (2017) examined the impact of physics teachers' PCK and motivation on the achievement and interest of the learners in Germany and Switzerland. Furthermore, a study by Mahler, Großschedl and Harms (2017) examined the relationships between science teachers' professional knowledge (CK, PCK and curricular knowledge) and the learners' performance in the context of biology teaching. The studies above found a positive relationship between the teachers' PCK and learner achievement (Lange *et al*., 2011; Alonzo *et al*., 2012; Mahler *et al.*, 2017) and between PCK and teacher motivation on student interest and achievement (Keller *et al*., 2017).

Furthermore, studies focused on American schools also revealed that teacher PCK seem to impact on learner understanding and achievements. With the focus on effective science professional development for teacher and student learning in American elementary schools, Roth, Garnier, Chen, Lemmens, Schwille and Wickler (2011) conducted a video-based lesson analysis. The participant teachers were observed in the classroom after the professional development programme in order to identify how the teaching strategies used linked PCK to students' learning outcomes (Roth *et al*., 2011). The analysis revealed a link between higher student gains and teachers' PCK about student thinking and teaching practices which aimed at improving the coherence of the science content storyline (Roth *et al*., 2011). Similarly, Sadler, Sonnert, Coyle, Cook-Smith and

Miller (2013) investigated the influence of teachers' knowledge on student learning in middle school physical science. The study revealed that knowledge of students' misconceptions (which is an aspect of PCK) positively predicted the learners' achievement gains (Sadler *et al*., 2013).

Moreover, a recent study by Akinyemi (2020) focused on South Africa, examined a PCK-learner outcome link with the focus on pre-service teachers. The study conducted an intervention (using a TSPCK construct) with 17 physical sciences pre-service teachers (PSTs) to develop their TSPCK on a topic of organic chemistry. By observing the PSTs' lessons, the researcher determined the participants' enacted TSPCK (eTSPCK) demonstrated in the actual classroom teaching and its influence on the learner outcomes (Akinyemi, 2020). The analysis found a positive significant correlation between the PSTs' eTSPCK and learner conceptual performance (Akinyemi, 2020).

Several other studies, however, did not find a link between the teachers' PCK and learner outcomes. For example, Cross and Lepareur (2015) investigated teacher-student interactions in relation to learners' difficulties. The investigation was intended to determine the relationship between a physics teacher's PCK and the learners' achievement on electric circuits in a French classroom. These researchers did not find any linear relationship between the teacher's PCK and student outcomes (Cross & Lepareur, 2015). Similarly, a study by Liepertz and Borowski (2019) investigated the relationship between physics teachers' professional knowledge (CK, PCK and pedagogical knowledge), interconnectedness of content structure and student achievement. The findings revealed limited learning gains in the pre-and post-tests and hence no significant differences in the Rasch measures (Liepertz & Borowski, 2019). Finally, Gess-Newsome et al. (2019) conducted a professional development intervention with 50 experienced biology teachers in one state in America. The researchers aimed to determine the relationship that the teacher professional knowledge (constituting academic content knowledge (ACK), the general pedagogical knowledge (GenPK), PCK and teacher practice) and the classroom practice has with student achievement (Gess-Newsome *et al*., 2019). While the analysis showed that the participant learners' achievement scores increased significantly from the pre-test to post-test, only ACK substantially influenced student achievement (Gess-Newsome *et al*., 2019).

The inconsistencies in the findings regarding the PCK-learner outcomes link has resulted in mixed signals to the PCK community. The reasons leading to these inconsistencies could be attributed to the differences in the PCK conceptualizations and methodologies employed by these studies. For

example, the two studies by (Liepertz & Borowski, 2019; Gess-Newsome *et al*., 2019) conceptualized PCK as discipline specific when dealing with specific topics. Furthermore, Liepertz and Borowski (2019) used paper-and-pencil tests to measure the professional knowledge (i.e., CK, PCK and PK) of teachers and the learners' achievement. While the paper-and pencil tests captured the teachers' planned PCK as per the PCK-RCM model, the teachers' lessons were also observed to portray their enacted PCK (ePCK). Gess-Newsome et al. (2019), on the other hand, measured the teachers' PCK through the written reflections, interviews and observations of classroom practice using a PCK rubric while the learners' achievement was measured from achievement tests drawn from a large test bank of items. The various methods of data collection used by Gess-Newsome et al. (2019) captured only the teachers' planned PCK.

Similar to Akinyemi (2020) in this study, PCK is conceptualized at a topic specific grain size, while using only content specific components without reference to generic components. This study associated the evidence of PCK with visible interactive use of these content-specific knowledge components when transforming the content knowledge in planning and classroom enactment (Mavhunga, 2020). While Akinyemi (2020) explored the PCK-learner outcome link on a traditional, B. Ed pre-service teachers; this study tracked the PGCE pre-service teachers (PPSTs) which is a one-year teaching programme. The PCK-learner outcome continuum link was examined through the cTSPCK-plTSPCK-eTSPCK continuum on a topic of Chemical Equilibrium. The significance of exploring TSPCK this way lay in the fact that very few studies have explored the entire continuum in a single study, particularly with PPSTs whose exposure to PCK and other pedagogies is limited to a single year as opposed to the 4-year period common to traditional pre-service teachers.

2.9. Teaching and learning of Chemical Equilibrium

An understanding of Chemical Equilibrium has been considered as crucial because it contributes to the understanding of other chemistry topics such as acid-base behavior, oxidation-reduction reactions and solubility (Bergquist & Heikkinen, 1990). Chemical Equilibrium, is however, perceived as a difficult topic consisting of abstract content (Tyson & Treagust, 1999; Ben-Zvi, Eylon, & Silberstein, 1987). Its difficulty is also associated with the words and language used. According to Bergquist and Heikkinen (1990), while the words used are taken from the everyday

language, their meaning is different. Furthermore, the abstract nature of Chemical Equilibrium concepts has resulted in a lot of common learner misconceptions (CLMs) which are found to be recurring in the literature. While the focus of this study is not necessarily on misconceptions or difficult concepts, the development of teachers PCK requires their deep understanding of the learners' conceptions and difficulties of a given topic (Van Driel *et al.*, 1998; de Jong *et al.*, 2005; Mthethwa-Kunene *et al.*, 2015). The relevant literature on CLMs and difficulties around Chemical Equilibrium is presented below.

2.9.1. Alternative conceptions and difficulty associated with the teaching and learning of Chemical Equilibrium

The abstract nature of Chemical Equilibrium has been argued in research as the cause for learner misunderstanding and conceptual difficulties (Ghirardi, Marchetti, Pettinari, Regis, & Roletto, 2015). One of the most recurring difficulties is that the learners fail to distinguish between complete and incomplete chemical reactions. Accordingly, the learners believe that the reverse reaction begins only when the forward reaction ends and this affects their understanding of the dynamic nature of equilibrium (Nìaz, 2001; Thomas, & Schwarz, 1998). Further difficulties are reported for understanding the constant nature of the equilibrium constant (Van Driel& Graber, 2002; Kousathana & Tsaparlis, 2002) and the unequal concentrations of reactants and products at equilibrium (Mavhunga & Rollnick, 2013; Ghirardi *et al.*, 2015). Similarly, learners also hold many alternative conceptions on the topic. While the consideration of the learner's prior knowledge is important in any teaching and learning situations (Gottheiner & Siegel, 2012), some learner preconceptions are alternative conceptions which contradict the scientific definitions (Kambouri, 2016). Some of these misconceptions are caused by the meaning of specific terms such as 'equilibrium', used in chemical equilibrium and have been found to have different meaning for different learners, (Bergquist & Heikkinen, 1990). Further, misconceptions are reported for: failure to distinguish between the rate and the extent of reaction (Banerjee & Power, 1991; Pekmez, 2010), mass or amount vs. concentration (Wheeler & Kass, 1978; Bergquist & Heikkinen, 1990) and the manipulation of LeChatelier's principle (Kousathana & Tsaparlis, 2002).

The value of knowing about the difficulties, misconceptions and preconceptions of the learners is to get insights of the concepts that need special attention and emphasis when teaching a topic. These considerations have transformative effects on the content; they influence the choice of

teaching strategies and representations by the teacher. Various teaching strategies have been suggested in the literature on how to curb the difficulties and misconceptions on the topic of Chemical Equilibrium. First, Van Driel, De Vos, Verloop and Dekkers (1998) suggested that the teaching strategies used should consider the learners' ways of reasoning and promote conceptual change. Wheeler and Kass (1978) recommend the use of graphs (concentration vs. time graphs) to help the learners to visualize what happens at equilibrium and when equilibrium is disturbed. Likewise, Huddle et al. (2000) suggested the use of simulations and analogies to assist with the conceptualization of abstract theoretical aspects. However, researchers warn that such analogies should be carefully selected as some of them may also reinforce alternative conceptions (Huddle *et al.,* 2000). Furthermore, Quilez-Pardo and Solaz- Portolez (1995) advised that teachers should use more exciting teaching strategies that promote problem solving competencies. This advice is supported by Bilgin (2006b) who noticed an improvement in conceptualization when pre-service teachers were taught in small groups that created opportunities for them to discuss both their misconceptions and new ideas.

The identified difficulties, misconceptions and the teaching strategies recommended in this chapter influenced the planning and the delivery of the intervention on Chemical Equilibrium in this study. As discussed in the theoretical framework guiding this study, transformation of content knowledge is at the core of PCK development. Furthermore, this study acknowledged the topic 'specificity' of PCK referred to as topic specific PCK (TSPCK). Therefore, the interactive use of the five content-specific knowledge components identified by Mavhunga and Rollnick (2013) demonstrated the quality of PCK in a given topic (Park & Chen, 2012). Moreover, an understanding of the interactive use of these components when explaining concepts was found to provide a teacher with pedagogical transformation competence that can be applied for a new topic. This understanding helped the study to track the development and manifestation of the competence gained by the PPSTs from the intervention into planning and classroom enactment in relation to learner outcomes.

Several data collection methods were identified as being appropriate for this study on PPSTs and on the effect of TSPCK on performance specifically. Therefore, the next chapter describes the methodology followed in this study.

CHAPTER 3

RESEARCH METHODOLOGY

This chapter describes the methodology and design used to investigate the development of the physical science PPSTs' topic specific PCK, as influenced by an intervention on content knowledge transformation, and its impact on their enacted TSPCK in real classroom contexts. I first present the research design and the rationale for its choice in this study. Unpacking the research design into its respective components follows. This includes the description of the study sample, which also includes their biography, the intervention procedure provided to the sample, the choice, nature and rationale behind the research instruments and tools used for data collection purposes. I then explain the Data collection procedure and describe the data analysis techniques. Finally, issues relating to validity and trustworthiness, the study limitations and ethical procedures inherent in this study are discussed.

3.0. Introduction

This research focuses on tracking the physical science PPSTs' TSPCK in planning, how it translates to enactment and its ultimate impact on learner achievement. The chapter begins by describing the research design and the rationale behind the choice of the design. Further, it unpacks the research design into its respective components, the sample of the study, the treatment provided to the sample during the duration of the study, the data collection procedures and the rationale behind the choice of the data collection instruments. The chapter then explains the data analysis procedures, the issues of validity and reliability, as well as ethical considerations and limitations of the study.

Some studies that explored the pre-service teachers' (PSTs) TSPCK development focused on the planned TSPCK growth (Mavhunga & Rollnick, 2013; Mavhunga *et al.*, 2016). Those studies also focused on the B.Ed. PSTs. Very few studies have conducted interventions with the purpose of tracking the teachers' TSPCK development in planning, translation into enactment and influence on learner performance (Akinyemi, 2020). Akinyemi's study focused on B.Ed. pre-service teachers. Also done at pre-service level, the present study will contribute to the already existing literature that describes the teachers' TSPCK across the three stages, with the focus on physical science PPSTs.

3.1. Research Methodology and Design

A mixed method has become more popular since its emergence over the past few years (Potter, 2012). It is a pragmatic worldview that involves the use of both qualitative and quantitative designs in the same study where data is collected concurrently or sequentially (Pelch & McConnell 2016; Halcomb, & Hickman, 2015; Creswell, 2014; Potter, 2012). Data is collected and analyzed using qualitative and quantitative designs and later integrated and inferences made (Potter, 2012; Creswell, 2014).

The argument is that the use of the two designs in one study provides a more detailed and better understanding of a phenomenon than an individual method, thus increasing its validity (Creswell, 2014; Potter, 2012; Lopez-Fernandez & Molina-Azorin, 2011). Argued in Creswell (2014), in mixed method research, *"the researcher bases the inquiry on the assumption that collecting diverse types of data best provides a more complete understanding of a research problem than either quantitative or qualitative data alone" (p. 48).* Venkatesh, Brown and Bala (2013) provide three benefits for using the mixed methods approaches: (i) its ability to simultaneously address confirmatory and explanatory research questions, (ii) providing stronger inferences than a single method and (iii) it affords an opportunity for the collection of divergent and/or complementary views. Cronholm, and Hjalmarsson (2011) argued that *"the use of a mixed method can also provide stronger evidence for a conclusion through convergence and corroboration of findings. By combining qualitative and quantitative approaches, or triangulate, the researcher's claim for validity of his or her conclusions are enhanced if they could be shown to provide mutual confirmation"* (p. 88). Its superiority over a single design includes the observation that it: (i) allows for a greater understanding of a phenomenon being studied by offering detailed information that might be missed when using only one research design and (ii) resulting in more reliable and relevant findings (Caruth, 2013; Cronholm and Hjalmarsson, 2011).

Creswell (2014) posited that, one of the values of this method lies in enabling the researcher to understand the impact of the intervention using both qualitative and quantitative measures. Using the pre-post-design, the use of a mixed methods approach allowed me to track the PPSTs' TSPCK across planning, its translation into enactment and ultimate impact on learner achievement as a result of an explicit intervention. An embedded mixed method design was used in this study. It was expected to yield pertinent results that can be trusted.

The study addresses three research questions, two of which are mainly qualitative in nature. The first two questions focus on explaining the PPSTs' TSPCK at the planning and enacted levels, respectively. The qualitative data collected assisted with unpacking their planned TSPCK and how this translated into TSPCK in action. The third research question focused on the link between the PPSTs' TSPCK and learner achievement. For this question, both qualitative and quantitative data were collected and analyzed for correlation. To reiterate, the use of multiple methods has an advantage of strengthening the analysis than the use of a single method. To analyze for question three, the correlation analysis was done to determine the relationship between the learners' performance in chemical equilibrium concepts and the PPSTs' TSPCK. The qualitative analysis succeeded the numerical analysis to provide a thorough understanding of the link that exists if any at all. Venkatesh et al. (2013) provided seven purposes for mixed methods research. These are complementarity, completeness, developmental, expansion, corroboration/confirmation, compensation, and diversity. Completeness and corroboration/confirmation are what led to the use of a mixed methods approach in this study. The qualitative data collected through observations and interviews ensure credibility of the findings and inferences made from the learner achievement tests. The use of data from the two strands also provides a holistic overview of the link between teacher knowledge and learner achievement.

Cautions have been made, though, concerning the challenges of using the mixed methods designs. They include analytical and interpretive issues which arise when one merges and integrates the data in concurrent designs (Creswell, 2014; Potter, 2012). Another challenge which could also arise during the data integration may be caused by an unequal emphasis that the investigator puts on each dataset (Potter, 2012). For this study, an equal weight is given to both qualitative and quantitative data in response to question three. More challenges portrayed in Creswell (2014) include the need for

> Extensive data collection, the time-intensive nature of analyzing both qualitative and quantitative data and the requirement for the researcher to be familiar with both quantitative and qualitative forms of research. The complexity of the design also calls for clear, visual models to understand the details and the flow of research activities in this design (p. 267).

Two raters who are familiar with both quantitative and qualitative methods were used to assist with the analysis and interpretation of results to ensure credibility and validity of the findings.

3.2. Research strategy

The study followed a group of physical science PPSTs. A case study research strategy was employed as it enabled the exploration of teachers' knowledge in order to gain a deeper understanding of the impact that the intervention had on their understanding and teaching of chemical equilibrium (Merriam, 1998). The use of a case study as a methodology in this case was deemed important as it enabled the collection of data using multiple sources (Rowley, 2002; Baškarada, 2014; Pearson, Albon & Hubball, 2015).

3.2.1. Case study

Yin (2003) defined a case study as an empirical enquiry that "investigates a contemporary phenomenon within its real-life context, especially when the boundaries between the phenomenon and the context are not clearly evident; and in which multiple sources of evidence are used" (p. 23). Case studies help the researchers to gain deep insights of educational situations such as classroom practices. According to Njie and Asimiran (2014), case studies are known for their ability to dig out for information and thus obtain characteristics of a particular entity of interest. For this study, a case study allowed for an investigation of the student teachers' knowledge transformation ability into forms more accessible to learners using video/audio recordings of the lesson presentations and interviews, lesson reflections, classroom discussions and their assignments. As argued in Rowley (2002), a case study enabled the use of a variety of data collection sources. Dealing with the complex and tacit nature of the PCK construct, it was important to use multiple ways of investigating this construct to unearth hidden information that a single method could not efficiently address or capture.

Merriam (2002), on the other hand, refers to a case study as involving a thorough description of a unit of analysis. The unit of analysis in this study is the physical science PPSTs' TSPCK. The focus is on how the TSPCK is developing in planning (plTSPCK), its evidence in the classroom context (eTSPCK) and impact on learner performance. The use of this approach enabled an investigation of cTSPCK-plTSPCK-eTSPCK continuum link to learner outcomes. Creswell (2012) refers to a case study as a bounded system, bounded by time and activity. This study focused on a PGCE class in a South African university, all registered for a physical science methodology course. This group was thus bounded by both time and activity in that, they all registered for a

one-year PGCE programme and attended the same physical science methodology module in the same university, in the same academic year, 2018. What bound the participants (the same academic year, 2018), is long enough to last until the end of the study (Yin, 2012; Creswell, 2014). Although this was a case study of a whole class of PPSTs, a subset of three teachers were later selected and observed teaching a chemistry topic and each teacher became a mini case. What bound the 3 PPSTs, although teaching in different schools, was the schools' agreement to have each of the three teachers deliver two lessons on chemical equilibrium to grade 12 learners for the duration of the study.

3.3. Participant selection/Sampling

The participants were a purposeful sample of physical science PSTs registered for the PGCE course. PGCE is a one-year full-time course of professional training for teaching which is recognized around the world (Hodgson, 2014). The students registering for this programme are usually specialists in other science disciplines with chemistry, physics, biology and geology as their major subjects (Kind, 2009). On acquiring PGCE, the PSTs are given a Qualified Teacher Status (QTS). The PPSTs are commonly assisted to learn to teach without much attention on content of that subject, based on an assumption that they have all the necessary content from their undergraduate or postgraduate courses (Hirst, 1980; Ogunniyi & Rollnick, 2015). The group that was followed for this study consisted of this special group of PGCE PSTs registered for (amongst other courses) a physical science methodology course which offers amongst other things, explicit development of PCK in core topics of physical science. McNicholl, Childs and Burn (2013) argued that "the main thrust of the PGCE course is to enable students to develop PCK by bringing their developing pedagogical knowledge to bear on their degree-level knowledge so that they can transform it for the classroom" (p. 156).

In their chemistry methodology course, the PPSTs are introduced to pedagogical transformation of content knowledge as a benefit of PCK. The underlying assumption is that by developing the competence to pedagogically transform content knowledge in a topic, they in turn develop PCK in the topic. The chemistry methodology lessons are presented by one University physical science Professor, who also teaches undergraduate methodology and content courses (i.e., chemistry content) in the same division of science.

All PPSTs registered for the physical science methodology course were approached and asked to participate in this study. During the intervention, the whole class of eight PPSTs was considered as a sample (purposeful sample) for this study. The group was considered as a case study in many aspects from the beginning to the end of the intervention that aimed to determine their acquired TSPCK. After the intervention, the PPSTs were assigned to schools around Johannesburg for their teaching experience. A subset of three PPSTs was selected because they were assigned in schools where they could teach chemical equilibrium at the time of the teaching experience. This was important because it allowed me to continue to track the TSPCK from planning, in enactment and its impact on learner performance. The three PPSTs were not necessarily representative of the whole class of PGCE physical science cohort. Rather, they were parallel individual mini case projects (Dumez, 2015) where the individual PPST's TSPCK at a planned level was checked against their enactment and learner achievement.

In South African schools, chemical equilibrium is taught in grade 12 and their access when it comes to research is close to impossible. It is also a common practice in South African high schools that the PSTs are not allowed to teach grade 12 learners during their teaching experience. This is because the learners are being prepared for their Final National Examination. The schools had to motivate against this provincial rule by the Provincial Basic of Education to allow this research activity to take place with their grade 12 learners. The selection of the subset of three PPSTs was therefore dependent on the schools' agreement to allow the PPSTs to teach this topic to their grade 12 learners. As my study had interest in TSPCK development and application, this cohort of PPSTs who were learning to apply TSPCK from a 'fast-speed one-year development track' were the perfect group and home for my study. Table 3.1 provides a detailed summary of the participants' educational background.

Table 3. 1: A Table of characteristic features of the PPSTs participating in this study.

Pre-service Teacher	Name of 1st degree	Year obtained	Major subjects	Name of 2nd degree	Year obtained	Major subjects	Current study
Mandla	BSc General	2017	Chemistry and Biology	X	X	X	PGCE
Jane	BSc Pharmacy	1995	Pharmaceutical Chemistry	X	X	X	PGCE
Daniel	BSc General	2012	Chemistry and Zoology	BSc Honors	2013	Zoology	PGCE
Katleho	BSc Material Science	2015	Material science and Chemistry	X	X	X	PGCE
Brown	BSc General	2016	Chemistry, and Physics axillary	X	X	X	PGCE
Noma	BSc Chemical Science	2005	Chemistry and Biochemistry	Postgraduate diploma in Public Management	2014	Public management	PGCE
Sara	BSc Geology	2016	Geology, Mining	BSc Honors	2017	Geochemistry	PGCE
Lerato	BSc Chemistry with Chemical Engineering	2017	Chemistry, and Process Engineering	X	X	X	PGCE

None of the PPSTs had any formal teaching experience. However, Mandla, Katleho and Noma had done some one-on-one tutoring to some learners in their communities. All of them were BSc graduates with at least chemistry as a major subject. All eight PPSTs indicated to have been exposed to the concepts of chemical equilibrium in their bachelor's degree studies, although the depths at which they had encountered them differed considerably. For example, Sara who did BSc Geology had been exposed to chemical equilibrium aspects prior to learning about thermodynamics (one of the modules offered in BSc Geology). In a class of eight PPSTs, six had recently obtained their degrees in BSc (less than five years before the year of this research study and before registering into the PGCE programme), except Jane and Noma who obtained their BSc degrees in 1995 and 2005, respectively. Both Jane and Noma had not been in the classroom before but had worked in non-educational sectors. This cohort of eight PPSTs constituted a larger case of the study. The data obtained from this group enabled the study to track the development of their TSPCK across planning, enactment and how it impacts on learner understanding of chemical equilibrium concepts. A subset of three PPSTs (shaded in Table 3.1 above) formed three individual

mini cases embedded, within a bigger case, that were observed in schools during the teaching experience.

A total of forty-three Grade 12 Physical Science learners, divided into three classes of fifteen, fourteen and fourteen who were taught by the three PPSTs were also participants in this study. All the three schools were located in the Johannesburg area and fell into the same category of South African schools called Ex Model C. This category is distinguished from other categories in that these schools were previously classified as white schools during the apartheid regime (Soudien & Sayed, 2003). Table 3.2 presents summarized information about the learner participants.

Table 3. 2: Information about the participant learners (N=43)

School Name	Pre-service teacher	Learners per PPST's class			
		Grade	Male	Female	Total
A	Noma	12	7	8	15
B	Lerato	12	7	7	14
C	Sara	12	9	5	14
Total			**23**	**20**	**43**

The study consisted of more male learners than female learner participants.

3.4. The Intervention

As hinted above, the training was an explicit intervention that normally happens in the physical science methodology course by virtue of its design. The course has a specific objective to develop TSPCK in core topics of chemistry and physics through a signature treatment (Mavhunga and Rollnick, 2017). The intervention typically runs over a period of six weeks, constituting three 1-hour periods in a week. A single topic is selected and retained through which the whole intervention is based. Throughout the intervention, the PPSTs were introduced to the framework of pedagogical transformation of CK. The framework consists of five TSPCK knowledge components that are content specific and work interactively to pedagogically transform CK into a teachable form. The components were discussed in the following sequence: first, (i) the concept of curricular saliency, followed by (ii) learner prior knowledge including misconceptions, then, (iii) what is difficult to understand in a topic, (iv) representations including analogies and (v) conceptual teaching strategies. At the end of the discussion of the TSPCK components, PPSTs were introduced to a tool to plan and to organize their thoughts about teaching. This was the

Content Representations (CoRe) tool developed by Loughran et al. (2004) to capture reasoning about teaching and portrays PCK. In the course, the CoRe is used as a tool to organize and capture the developing thoughts about teaching a topic. Participants completed tutorials and the CoRe in the topic of the intervention as part of learning and formative assessment. In acknowledgement of the importance of the training discussions to the study and the interpretation of the findings, a detailed description of the intervention is discussed in a dedicated chapter, Chapter 4, detailing how the intervention evolved for this specific group of PPSTs.

3.5. Tools and Instruments

Collecting data through multiple sources assisted with ensuring the reliability of the study. Three different sets of instruments were used. The first set of instruments included *pencil and paper instruments*. These comprised CoRe tool, a specially designed chemical equilibrium TSPCK test and learner achievement tests. The second category was through *an interview protocol and audio recorder* that guided my interviews and capturing of responses. The last one comprised the use of *video recording during the lesson observations.*

(a) Administering Pencil and Paper instruments

The pencil and paper instruments administered in this study are a content representation (CoRe) tool on chemical equilibrium, specially designed chemical equilibrium TSPCK- test tools, the learner achievement content knowledge (LACK) tests, as well as the learners' views. As argued in research, pencil and paper instruments are not only reasonably economical (Malcolm, 2018) but are also known for their simplistic nature, which makes them easy to use Mavhunga (2012).

(i) CoRes

A case study enables the researcher to collect data as the process unfolds in order to develop an insight about the manner and pathways of learning followed. CoRe is a special tool used in the intervention to organize and capture the reasoning about teaching. It was used in this study and considered as a tool that portrayed the developing PCK in the topic of the intervention. The structure of a CoRe consists of prompt questions that enable teachers to think through their subject matter content as they plan to teach every topic. It enables the teacher to think in depth about discussing topic content, conveying their explicit understanding of the main ideas around the topic

(Loughran *et al.,* 2004; Alonzo, Berry, & Nilsson, 2019; Henze & Barendsen, 2019). To be more explicit, the use of CoRe allows one's response to be more elaborate and can provide a detailed overview of the teachers' knowledge for teaching a topic. The tool's reliability and validity for efficient use, has been seen in its ability to portray the teachers' personal PCK (pPCK) and enacted PCK (ePCK), and in assisting the researchers to understand the teachers' own knowledge and understanding of the topic, as observed in Henze and Barendsen (2019) and Carpendale and Hume (2019). A CoRe used in this methodology course has been adopted from that by Loughran et at. (2004) and slightly modified to meet the objectives of the course, see Appendix B for a complete view. This has been modified to include all five TSPCK components of content knowledge transformation and has thus been used as a teaching tool in this course (Mavhunga & Rollnick, 2013). This CoRe has been used in several studies that attest to its reliability and efficiency in capturing data to explain the teachers' pedagogical reasoning about a topic (Mavhunga, 2014; Mavhunga *et al.,* 2016; Pitjeng-Mosabala & Rollnick, 2018).

Time and place of use: A CoRe tool was administered by the researcher in the chemistry methodology class during the intervention period. The CoRe was based on one topic (chemical equilibrium) - the same topic that was used in the intervention. The CoRe developed by the PPSTs was given in the form of an assignment towards the end of the intervention. This assignment was submitted two weeks after the intervention.

(ii) TSPCK tool for Chemical Equilibrium

This is a tool that has been designed specifically for capturing the teachers' topic specific PCK on the topic 'chemical equilibrium'. It is structured such that it addresses (amongst other things) the five TSPCK components (Mavhunga & Rollnick, 2013). This tool, which was developed and validated in Mavhunga (2012), has also been used in several studies which indicate its reliability and validity in capturing the intended/aspired data (Mavhunga & Rollnick 2013; Mavhunga & Rollnick, 2016; Mavhunga 2018). Each item has between two to three items that talk to it in the form of questions. Different from the CoRe which requires teachers to formulate their own responses, the TSPCK tool has a list of responses to choose from. For example, on a component regarding "learner prior knowledge and misconceptions", there is a list of responses from which the teacher selects the best (see an extract in Figure 3.1) to give to a learner who has a doubt about

a particular concept on the topic. The selection of the best response is followed by an expansion from the teacher explaining why their chosen response is more fitting to the question asked (refer to Appendix A for a complete overview). The teachers' responses to this tool provided an overview of their understanding of the topic, and their ability to think about and reason through their content using the five TSPCK components. Responding to the questions in this tool does not only require the teachers' understanding of the five content-knowledge components of transforming the topic but it also requires the ability of the teacher to interactively use the components when responding and explaining other questions within the tool.

CATEGORY A:

1. In a classroom setting, which of the following responses will you choose to answer a learner who seems to be in doubt and asks you:

"Do both the forward and the backward reaction actually take place if a closed system is at equilibrium?"

Response A: Yes; the rate at which the forward reaction occurs is the same as the rate at which the backward reaction occurs. We do not see them because both reactions happen under a microscopic eye.

Response B: Yes; for a reaction to be considered as at equilibrium, the rate of the forward reaction is the same as the rate of the reverse reaction. As products are formed, they decompose or react with each other and form reactants. In this way the reaction is kept at equilibrium.

Response C: Yes; a reaction that is at equilibrium has a forward and a reverse reaction. The forward reaction produces products, and the backward reaction produces reactants. Sometimes the concentration of products is higher than reactants, sometimes vice versa.

Response D: None of the above.

Choose your response and use the space below to expand on your choice.

Figure 3. 1: A TSPCK tool extract on chemical equilibrium

Time and place of use: The researcher administered this tool twice, before and after the intervention. The first tool was issued on the first day of the chemistry methodology class, before the intervention began. The second one was completed after the intervention (given in the form of an assignment) and submitted a week after the intervention.

(iii) Learner achievement content knowledge (LACK) test

The learner achievement test on chemical equilibrium was compiled from a set of questions extracted from the South African National Examination question papers. Extracting content from the valid content tests such as the National Policy Examination Papers (Physical science paper 2, 2015) ensured for validity of the content captured by the tests. The test consisted of three multiple choice questions totaling three marks (covering 25% of the test) and four long questions, that added up to a total of nine marks covering 75% of the test (refer to Appendix D for a complete overview). Two aspects of chemical equilibrium (relative to what the pre-service teachers were expected to teach in the classroom) were included in the learner achievement instrument. These included concepts relating to the conditions necessary for the chemical equilibrium to be attained including dynamic equilibrium, and factors that affect the state of equilibrium, and the Le Chatelier's principle which stems from the concept of disturbing the state of chemical equilibrium. Table 3.3 summarizes the content captured by each item in the learner-achievement test.

Table 3. 3: Description of the content covered in the learner-achievement test.

Test Item	Content Description
Item 1	Rates of reactions at Chemical Equilibrium
Item 2	The effect of increase in the yield of products for exothermic reactions
Item 3	Concentration of products at Chemical Equilibrium
Item 4	Effects of a disturbance at Chemical Equilibrium
Item 5	Drawing a concentration versus time graph to demonstrate Chemical Equilibrium
Item 6	Explaining what is an open system
Item 7	Explaining what is a closed system
Item 8	Explaining reversible reactions
Item 9	Explaining dynamic equilibrium
Item 10	Rate of forward and reverse reactions at Chemical Equilibrium
Item 11	Effects of increasing the concentration of product to a reaction that has reached Equilibrium
Item 12	Explaining the response to Item 11 using the Le Chatelier's principle

For example, one of the questions asked in the test read: *"What happens to a chemical reaction that has reached an equilibrium state when a disturbance is added?"* (Department of Basic Education, Physical science paper 2, 2015). The purpose of the test was to help the researcher to use the learner achievement in order to determine the relationship between the PPSTs' eTSPCK observed in their actual teaching and learner performances.

Time and place of use: The learner achievement test instruments were administered in the classroom as pre and post-tests to determine the effect that the student teachers' TSPCK quality has on learner achievement.

(iv) Learners' views

It has been argued in the literature that knowledge of the learners' perspectives can enable teachers to understand and hence appreciate the instructional processes that influence students' learning including how to improve their teaching processes (Senocak, 2009; Halim, Abdullah & Meerah, 2013). This supports the understanding in the literature that learners' views can also be used to get information on the quality of their teachers' PCK (Halim *et al.*, 2013). It was through this understanding that the study explored from the learners' perspective, things that the PPSTs did to promote or to hinder their understanding of the concepts. Adopted from the validated tools designed by Senocak (2009) and Halim et al. (2014), a sample of questions on learners' views is presented in Figure 3.2. The questions on learners' views were checked by two experienced chemistry teacher educators who are also PCK specialists for validity. The aim was to check if the questions had the capacity to elucidate the quality of PCK demonstrated by the PPSTs in their teaching.

1. What did the student-teacher do, that helped you to understand the concepts? Give an example
2. What was done in the class by the student-teacher that you liked most?
3. What was done in the class by the student-teacher that you did not like?
4. What do you think would help you to understand better?

Figure 3. 2: Questions on learners' views

Time and place of use: The questions were administered to learner participants across the 3 PPSTs' classrooms.

(b) Interview protocol and audio recordings

An interview protocol is a set of questions used to elicit specific information from the participants in a consistent manner. The interview, which was mainly a stimulated recall, was based on and triggered by the PPSTs' lesson episodes as they explained and answered the learners' questions in their teaching. As postulated in Jewitt (2012), "Video elicitation can be a useful way for researchers to validate and cross check their interpretations when working with video of 'naturally occurring' interactions" (p.3). It allows the researcher to integrate video interpretations with teachers thought processes and reasoning that they provide during the interviews (Asan & Montague, 2014). Where there was an observable contrast between what is presented in a lesson plan versus, the actual classroom teaching, such an extract was used as a stimulant to help understand the disparities. So, the questions were generated later in the study, after collection and analysis of classroom observations and their corresponding lesson plans. It was through these interviews that explanations regarding some of the classroom observation occurrences and challenges encountered during the lesson delivery could be described. The interview questions on this protocol were developed in consultation with my supervisor. Appendix C illustrates the interview schedule used in this study. On developing this interview protocol, reference was also made on how to generate an interview schedule that encourages respondents to present their thoughts and ideas with "greater richness and spontaneity" (Opie, 2009: 112), examples of interview questions (Opie, 2009; Wagner, Kawulich & Garner, 2012) and on the commonly asked questions during the lesson interviews (by other researchers), specifically those aimed at evaluating the teachers' PCK in action (Malcolm, 2018).

Time and place of use: The follow-up, stimulated-recall interviews were administered by the researcher post the lesson observations on chemical equilibrium. These were administered to a subset of three PPSTs who were observed teaching the topic of intervention to grade 12 learners, in the researcher's office. All the interviews were audio recorded to capture the responses.

(c) Video recordings

All lesson observations were videotaped, and interview sessions audiotaped. Video recording ensured accurate capturing of both movements and audio statements by the PPSTs and their learners during the classroom teaching. It enabled the researcher, to identify the occurrences of

TSPCK episodes during the lessons. Recordings also enabled the researcher to replay the videos/audios again and again during the data interpretation (Penn-Edwards, 2004), reducing the possibilities of PPSTs' misrepresentations and bias by the researcher. According to FitzGerald (2012), data captured using a video contains rich information which could reveal very important incidents relating to what is being investigated. The replays were also done by my supervisor to ensure data reliability and trustworthiness. One of the disadvantages of observations is the presence of the researcher; according to research, this might influence how the participant behaves, thus impacting negatively on the data outcome (Leedy & Ormrod, 2001; Asan & Montague, 2014). Taking a video might also cause a disruption to the lesson (Creswell, 2014). The use of follow-up interviews was thus helpful in mitigating this shortfall by assisting the researcher to validate the data and cross checking the interpretations of the video recordings. The camera was placed at the back of the class, so that the learners' focus would not be directed away from the teacher onto the video recorder. The audio recording of the interviews not only captured the statements made but could also be replayed later in the data analysis to prevent misrepresentation of the participants. Data capturing using videos and audios that were later replayed was done with the purpose of not only confirming the reliability of the data but also its dependability. One disadvantage for both video and audio recordings is that they produce massive data that requires a lot of time to transcribe and interpret (Opie, 2009). To reduce this burden, transcriptions were made after every recording to prevent any eccessive and uncontrollable accumulation of data. Observations and interviews were not scheduled on the same dates. This also provided adequate time and space for the transcription to be made.

Time and Place of use: Video recording was made during the teaching experience for all the lesson observations. Later in the analysis, all the three PPSTs who were observed teaching were also interviewed. All the lesson video records and interviews were administered by the researcher.

3.6. Data Collection

In order to track the PPSTs' TSPCK from planning into classroom enactment and its ultimate influence on learner performance, data was collected at five different stages of the study. These were: before the intervention, during the intervention, immediately after the intervention, two weeks after the intervention during the classroom observations and, lastly, after the lesson

observations. Figure 3.3 provides a pictorial summary of the data collection points and the nature of the collected data.

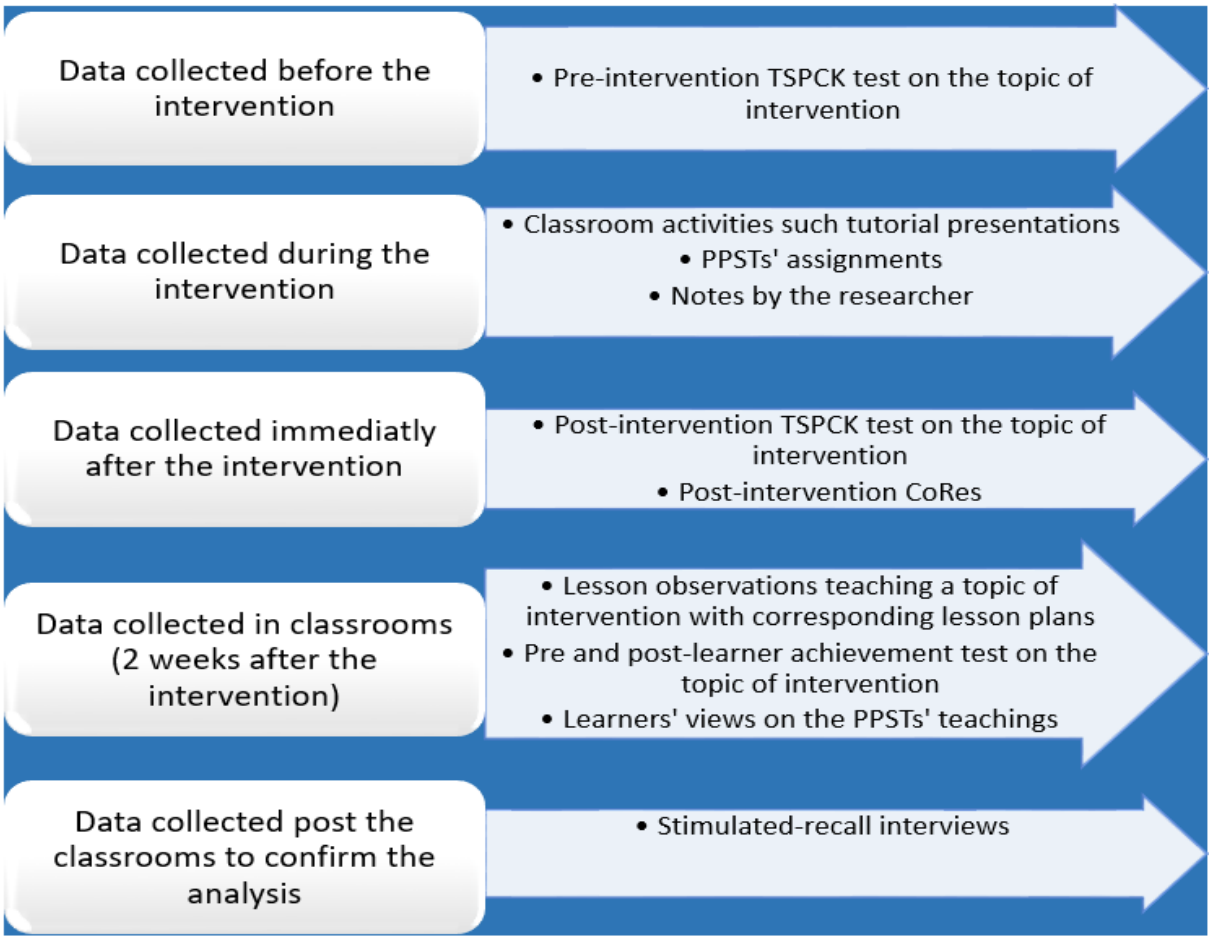


Figure 3. 3: Procedural summary of data collection steps

Stage I: Before the intervention *(working towards Research Question 1)*

A pre-intervention TSPCK test was administered on chemical equilibrium before the intervention began. This is a specifically designed TSPCK tool for capturing the teachers' topic specific PCK on chemical equilibrium (Mavhunga & Rollnick, 2013). The responses to this tool provided an overview on their understanding of the topic. It established a credible baseline of the knowledge that the participants bring with respect to the content of the intervention. This allowed for a reference to interpret all other analyses.

Stage II: During the intervention *(working towards Research Question 1)*

The purpose of the data collected during the intervention was to assist the researcher in capturing the evidence of highlights/indicators of pTSPCK as it is developing. It provides an insight into the patterns of development as the intervention progressed. Throughout the intervention, the PPSTs engaged in tutorial presentations and discussions relating to individual TSPCK components. The tutorials were aimed at assisting the PPSTs with the development of their pedagogical reasoning competence (TSPCK quality) and in, possibly, deepening their content knowledge and understanding of the topic of intervention (Pitjeng-Mosabala & Rollnick, 2018; Rollnick, 2017). The tutorial presentations and discussions provided opportunities for them to showcase their understanding and interpretations about the individual components and how each component interacts with others (which usually happened at the end of a discussion of each component). All the tutorial presentations and discussions were thus captured through audiotapes and their corresponding presentation slides collected. Accompanying these were the thick notes documented by the researcher, and the snapshots of demonstrations done on the board which could not be captured on audio. Therefore, both the tutorials presentations and submissions gave an added insight to the evidence of pTSPCK as it was developing. This was important in supporting and confirming the evidence of shifts seen between the pre- and post- TSPCK tests.

Stage III: Immediately after the intervention *(working towards question 1)*

A post-intervention TSPCK test on chemical equilibrium and a CoRe tool were administered to all PPSTs at the end of the intervention. A TSPCK-test tool administered at the end of the intervention was similar to that which they completed prior to the intervention. The purpose of the post-TSPCK tests was to determine the shifts in plTSPCK quality of the PPSTs, using the pre-tests as a base of reference. The post-intervention CoRes and data collected in stage II above was used to corroborate the findings on the shifts from the TSPCK tests.

Stage IV: In the classrooms (*working towards Research Questions 2 and 3)*

At this stage, data was collected from two different groups of participants: (a) the PPSTs, and (b) their learners. This third set of data was collected in the field during the teaching experience (TE) with a subset of 3 PPSTs and the learners that they were teaching.

a) Data from PGCE Pre-service teachers

Data collected from the PPSTs included video recordings of two lessons per participant teaching chemical equilibrium as well as their corresponding lesson plans. Follow-up sessions to the observed lessons were face-to face interviews asking questions that were intended to clarify the PPSTs' lesson plans, their intentions and some of the occurrences considered interesting and captured during the lesson observations (post-lesson interview, see Appendix C). The participants were observed in their action of teaching with the purpose of examining the translation of content knowledge transformation from planning to classroom teaching. The data collected through observing actual classroom teaching helped to establish the emerging patterns and pathways in which intentions from the lesson plans are acted out in real classroom. With these data, the relationship between the PPSTs' plTSPCK and eTSPCK in action was described. One of the advantages of observations and qualitative designs is flexibility, enabling the observer/researcher to shift their focus as new data resurfaces (Leedy & Ormrod, 2005; Creswell, 2014). According to Leedy and Ormrod, observations, however, do have some disadvantages. One of the disadvantages they discussed is that "the very presence of the observer may influence her/him to change what the participants say or do and how significant events may unfold. Another disadvantage of observation that was put forth is that researchers often write insufficient notes of what they have observed which do not completely reflect the reality" (158). In order to be as objective and detailed as possible it is hoped that the collection of complementary data as thick notes and interviews will help to capture the events holistically. This data therefore assisted with tracking how the PPSTs plTSPCK translated into eTSPCK.

b) Data collected from the learners

Pre-and post-learner achievement tests were administered to the learners before and after they were taught on the topic of chemical equilibrium. The learners had not received any teaching on the topic before the PPSTs' teaching. The learners' views regarding the PPSTs' teachings were collected immediately after the post-achievement test to determine what contributed to or hindered their understanding of content. The data collected through the learners' pre/post-tests and their views enabled the researcher to evaluate the impact that the teaching had on the learners' understanding of the concepts of chemical equilibrium. It was through the analysis of these data

that the relationship between the PGCE pre-service teachers' TSPCK in the actual classroom teaching and learner achievement could be examined.

Stage V: Post lesson observations *(working towards research questions 1, 2 and 3)*

The fifth set of data was collected through follow-up, stimulated recall interviews. Stimulated recall interviews involve showing a piece of work previously collected from the participants and asking them first to recall it, and then answer the questions seeking the reasoning employed at the time of the data collected. The data used was extracted from lesson plans and the actual lesson observations. At this stage, extracts of evidence from lesson plans and recordings were re-played to stimulate participants' minds and elicit reasons behind observed actions. Questions asked sought to understand the PPSTs' thinking behind their actions in the classroom in response to the learner questions or on explaining certain concepts of the topic (see Appendix C). Understanding the reasoning behind their way of thinking and practice enabled me to evaluate and explicate the PPSTs' quality of pTSPCK on the topic of intervention. The second purpose for conducting stimulated recall interviews was to confirm the patterns observed as possible pathways which participants use to move from pedagogically transforming a topic of intervention at a planning level into the classroom practice contexts. This action also improved trustworthiness of the ensuing analysis. The interview questions used in all the interviews were semi-structured and the questions were all prepared in advance. The interviewer probed questions during the interview sessions for clarification. Probing ensured that the interviewees would not go too far-off track. This approach was employed in accordance with research (Creswell, 2014; Brooks & Normore, 2015) which contends that some forms of interviewing depend on an interview guide.

3.7. Data Analysis

This study examined the PPSTs' TSPCK continuum link to learner outcomes by following the development of TSPCK in PPSTs through the cPCK-plPCK-ePCK trajectory on a topic of Chemical Equilibrium. To do this, the analysis was done in 4 separate stages. The first stage examined the extent of the development of the PPSTs' plTSPCK as a result of the explicit intervention (cTSPCK). This was important to establish the baseline from which the evidence of TSPCK could be tracked into the different teaching settings, as in planning to teach, translation into enactment and the ultimate possible influence of enactment on learner achievement. The

second stage assessed how the PPSTs' plTSPCK developed at the planning stage translated into action (eTSPCK). The third stage examined the learners' performance in the learner-achievement tests. This was done by looking at the extent of knowledge gains following the PPSTs' teaching on the topic. The last stage examined the influence that the PPSTs' eTSPCK had on learner outcomes. It focused on the correlation between TSPCK and the learners' conceptual performances. Figure 3.4 illustrates the four different stages involved.

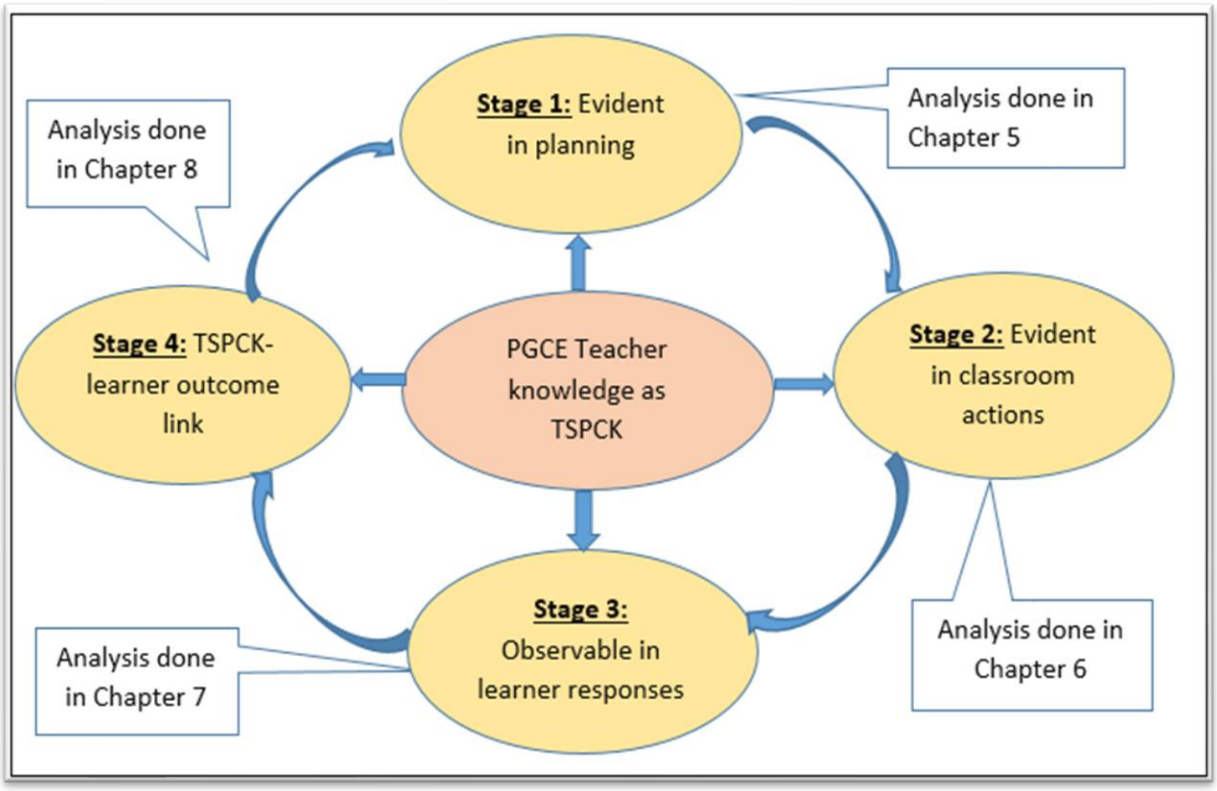


Figure 3. 4: Summary structure of the analysis chapters

A glimpse onto Figure 3.4 points out that the first chapter of analysis described the PPSTs planned TSPCK; chapter 6 looked at the PPSTs' TSPCK in action, observed as the PPSTs taught in normal classroom contexts. Chapter 7 discussed the pre- and post-learner performances in learner achievement tests. Finally, Chapter 8 discussed the possible link between the PPSTs' enacted TSPCK and learner performance.

3.7.1. Analyzing for the extent of the development of the PPSTs' TSPCK in planning

(i) Analyzing for patterns suggestive of shifts in quality of TSPCK

The first stage of analysis was focused on identification of presence and shifts in plTSPCK quality in the topic of intervention captured on the TSPCK-test tools before and after the intervention. The tools were used to elicit the PPSTs' TSPCK from the point of reasoning in planning to teach. An in-depth qualitative analysis method was used to unpack the data that explained the quality of teacher development and hence their plTSPCK as a result of the TSPCK construct. At this level, the analysis of the shifts in plTSPCK quality was explained, using pre- and post- TSPCK-test tools. The analysis further drew on data from the tutorial presentation data and post CoRes, used as complementary data to ensure reliability and validity of the results. The observed shifts were compared to the evidence of the findings emerging from the analysis that was done during the intervention to confirm or contradict the patterns.

First, the TSPCK tests were scored using an adapted and peer validated TSPCK rubric by Mavhunga (2012) to locate the quality of the PPST's response. The rubric which consisted of the five components of TSPCK was designed specifically for capturing the teachers' TSPCK at a planned level. It is a four-criterion based pTSPCK rubric, with scores ranging from 1 to 4 (see Appendix F). The prompts within each category which explain the level of interaction between TSPCK components were used to determine the quality of TSPCK. A score of 1 was assigned to a limited quality of TSPCK; score 2 was assigned to a basic quality; score 3 was assigned to a developing quality whilst the highest score of 4 was assigned to an exemplary quality of TSPCK. Scoring of these tests happened with the assistance of two independent raters, where each was provided with unmarked scripts/tests for all the eight PPSTs to improve the reliability of the scores. The raters were people who had done similar studies before, and therefore had all the necessary skills with respect to the TSPCK framework application, as well as that of Chemical Equilibrium (the topic of intervention). Where inconsistencies with the scoring occurred, the discussion was held, and consensus reached on the score to be awarded to the PPST. The scores awarded by the researcher and the independent raters were validated by calculating the Kappa-Cohen inter-rater reliability index (Landis and Koch, 1977). The overall agreement rate of 0.86 was obtained between the raters. Scoring by all the raters followed three rules which have been used by other

researchers. The rules were: (i) a score corresponding to the category in the rubric where most criteria were met was assigned singly for each question; (ii) a question with no response was assigned the lowest score of 1; (iii) a question with responses falling across two categories that are close to each other were scored by checking specific gate-keeping criteria as in the shaded part of the rubric extract in Figure 3.5.

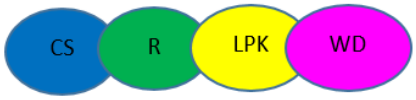
Limited (1)	Basic (2)	Developing (3)	Exemplary (4)
• Identifies broad topics without specifying the actual sub-concepts that are problematic • Reasons not given	• Identifies specific concepts but provides broad generic reasons such as 'abstract' • Reasons drawing on one other component of TSPCK	Identifies specific concepts with reasons related to two other TSPCK	• Identifies specific concepts with reasons related to prior knowledge of specified students and aspects of curricular saliency • Provides reasons linking to specific gate keeping concepts that when not fully understood adds to the difficulty of a concept regarded as difficult – thus drawing on three or more TSPCK components
Note: *The score of 1 represent a limited TSPCK quality (indicating the use of one component of TSPCK in an explanation), 2 indicates a basic TSPCK proficiency (representative of an interactive use two components of TSPCK), 3 indicate a developing level of proficiency (as the teacher interactively uses three components of TSPCK in an explanation), and 4 represents an exemplary level of proficiency (evident of use of four components in a task, or an explanation)*			

Figure 3. 5: An extract for the rubric for quantifying PCK (Mavhunga& Rollnick, 2013)

The scores allocated were then described, using the matching qualitative responses given by the PPSTs on the test tools. To do this, TSPCK episodes extracted from the TSPCK test-tools were identified and used to explain the quality of PPSTs' plTSPCK. In this method (Park and Oliver, 2008), each segment is analyzed for its composition of TSPCK components, frequency of occurrence for each component, sequence of emergence of the components across the teaching segments and the extent of interactions among the components. These episodes were then pictorially presented, using the adapted PCK Maps (TSPCK Maps in this study) for visual purposes and clarity of the identified episodes (Park & Chen, 2012). This was done with the purpose of providing the reason to the allocated scores. TSPCK Maps were drawn where PPSTs had interactively used two or more TSPCK components in their explanation of a concept. The interactions between components were observable in the explanations provided for TSPCK components such as learner prior knowledge and misconceptions (LPK), the use of representations (R), concepts considered difficult to understand (WD) and conceptual teaching strategies (CTS). The extract below provides evidence of the shifts in the PPST's reasoning quality seen in the explanation that the PPST provided. Figure 3.6 presents an example of a TSPCK episode extracted

from a response given by one of the PPSTs on a component of what is difficult to understand, followed by a pictorial demonstration of the components interacting.

Dynamic equilibrium- in chemical systems (and that the rate of the forward reaction is equal to the rate of the reverse reaction)	Dynamic equilibrium- **i.e. A reversible reaction contradicts their prior knowledge that reactions are of the form R → P (i.e., not A + B ↔ P) and go to completion. If no observable reaction is taking place, then learners may find it difficult to accept/believe that 2 reactions are indeed taking place (forward and reverse reactions) and that these are occurring at the same rate. (Abstract and non-intuitive). There are many misconceptions associated with this concept, and this concept links to several subordinate concepts**



Post-test TSPCK Map describing what is difficult

Figure 3. 6: A TSPCK episode extract on what is difficult to understand: an extract from a TSPCK tool

Looking at Figure 3.6, the explanation that the PPST provided on why a dynamic equilibrium is considered difficult for the learners to comprehend consists of an interaction between four TSPCK components. An interaction between four components scored this kind of episode at an exemplary level, the highest score demonstrated on the rubric. This indicates a sophisticated kind of TSPCK quality by the PPST on this component. To illustrate this interaction pictorially, a TSPCK Map below the extract enables the researcher to visualize the order in which the components are used in an explanation given.

The analysis focused on both sets of TSPCK test-tools (pre- vs post-tests). Data from the CoRes and tutorial presentations was used as complementary data, providing depth and more insight to specific episodes identified from the TSPCK-test tools. These data were used to corroborate the findings from the TSPCK tests. To analyze for TSPCK development during the intervention, data obtained from the PPSTs' tutorial presentations and discussions captured during the intervention were used. A great focus was on the explanations provided by teachers that indicate their TSPCK quality across the various components of content knowledge transformation variables. An analysis of pre- and post-intervention data, as well as tutorial discussions enabled a more detailed description and analysis of the impact that the intervention had to play and affected their planned TSPCK on this chemistry topic.

(ii) Analyzing for evidence of developing plTSPCK during the intervention

The analysis focuses on the explanations and interpretations of components given by the PPSTs to illuminate their understanding of the individual components and how the components interacted with each other. The presentations were in the form of slides or charts, all aiming to elicit the PPSTs' understanding of individual TSPCK components. The data from these tutorials and CoRes are used to corroborate the findings from the TSPCK tests. This allows for the study to explain the shift in the quality of plTSPCK as it was developing during the intervention. An in-depth qualitative analysis was used to explain the PPSTs' presentations further in order to illuminate their understanding of the individual components of TSPCK and their ability to use them interactively in an explanation. For example, on a tutorial that was based on learner prior knowledge and misconceptions, one interesting extract by a pair of PPSTs Jane and Sara is discussed to show their interpretations and understanding of the component. The pair did a presentation that dealt with one common learner misconceptions that "there are no reactions taking place at chemical equilibrium". Their response below is based on how they addressed this kind of misconception. For example, Sara argued:

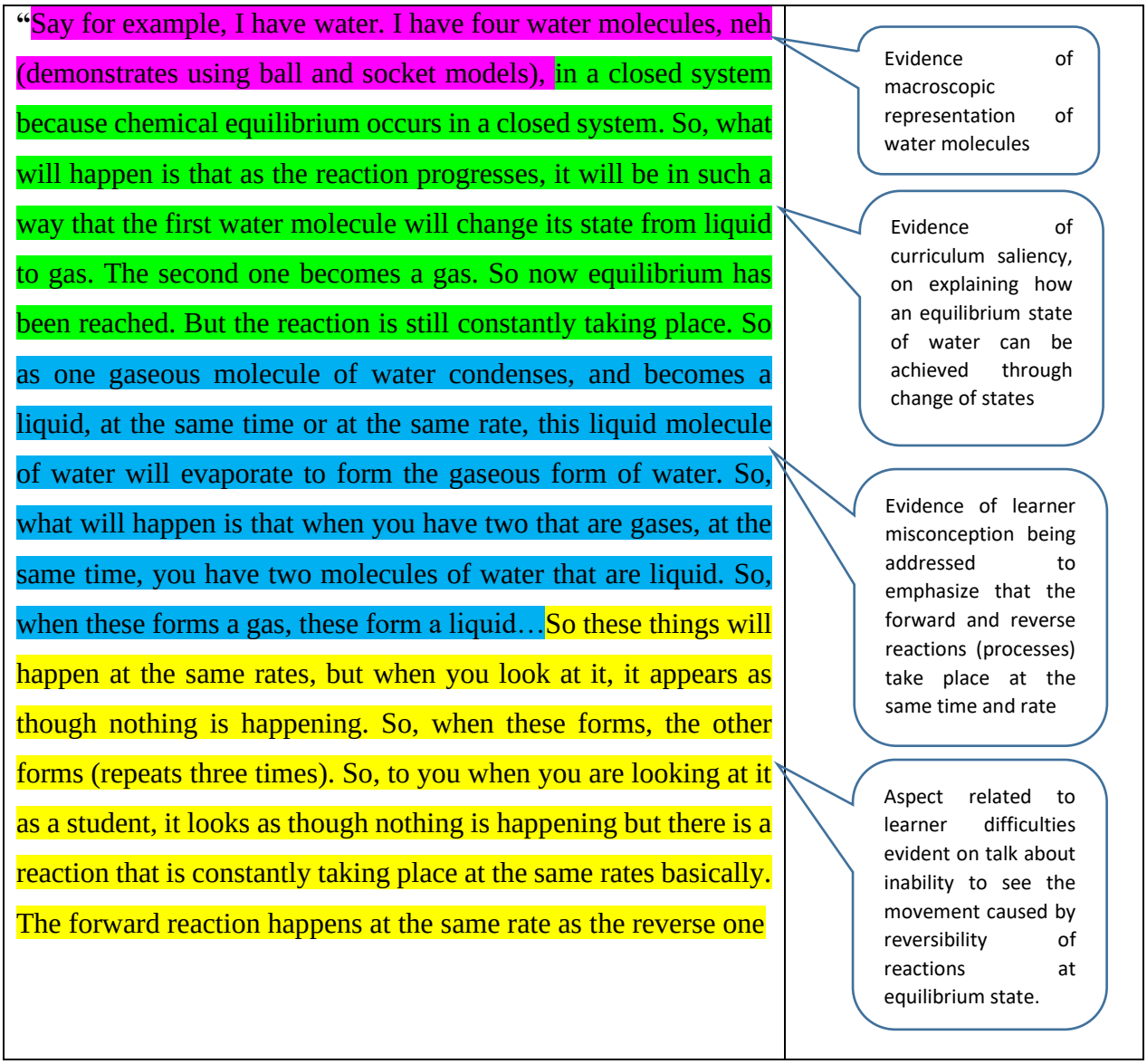


Figure 3. 7: A Tutorial extract by Jane and Sara on addressing a learner misconception

The extract above indicates the ability of the PPSTs to interactively use multiple components of TSPCK to address a common learner misconception. The PPSTs were only asked to address a learner misconception, but from the explanation given, it shows that they comprehended what was explicitly emphasized during the intervention that, even though the discussions are on individual components, their applicability is seen in their interplay with each other in an explanation. The extract shows an interplay of three other TSPCK components (representations, curriculum saliency, and what is difficult to understand), all aimed at helping the learners to understand that both forward and reverse reactions take place at the same rate when the reaction has reached an equilibrium state.

Although in this explanation, the pair appears to be using representations, a concern was raised by the educator during this presentation on the choice of representations. It was emphasized that the choice of representations should be such that they do not promote further or create more learner misconceptions. An example was made with the use of the ball and socket models that displayed two gaseous molecules of water and two liquid molecules at a state of equilibrium from the explanation given by Sara above. According to that illustration, this is likely to enhance the already existing misconception that "concentrations of both reactants and products are equal for all reactions that have reached an equilibrium position". A video that displayed a similar scenario that should be avoided when selecting materials that are aimed at enhancing learner conceptual understanding was then played for the PPSTs, followed by a video that displayed varying concentrations of reactants and products for emphasis purposes.

As one PPST noted: "…*so it means that reactions that have reached equilibrium do not necessarily have equal concentrations of reactants and products, although there are cases when they are equal*"? In response to this, it was indicated that it is essential to ensure that, on explaining this to the learners, emphasis is made that concentrations of reactants and products differ. Although they remain constant, the rates of reactions are equal. Emphasis was made that it is important to make clear to the learners and help them differentiate between "*what is equal, versus what is constant between rates of reactions and concentrations of reactants and products*". This shows that concentrations do not necessarily have to be equal for reactions to reach an equilibrium state, although they will always remain constant.

As the intervention progressed, the PPSTs did a CoRe in the form of an assignment. One of the prompts that they were responding to dealt with conceptual teaching strategies. The component required PPSTs to describe the teaching strategies that they planned to use in order to teach specific concepts around one Big Idea. The extract below was taken from Sara's CoRe designed to address the concepts around the dynamic nature of chemical equilibrium. This Big Idea includes concepts that include the conditions necessary for the equilibrium state to be attained. This was analyzed by looking for the presence and use of the components in an interactive manner. This is how Sara presented her strategy with interplay of four TSPCK components:

> "…*explain dynamic equilibrium using the closed water bottle experiment hand in hand with the ball and stick models to show how evaporation takes place, eventually leading to*

condensation on the upper surface of the water bottle, eventually forming water droplets that move down the sides of the bottle. I would make students aware of the fact that not all the water evaporates before condensation starts showing that the reaction did not go to completion before the inception of the reverse reaction. I would then show a live video demonstration of the water level in the closed bottle not changing over time. This serves as proof that the rates of the forward and reverse reaction are now equal. That is why there is no macroscopic observable change and why no matter is lost. Energy shifts (not loss) take place".

The explanation given in the above strategy is much more precise and clearer than what the PPSTs presented in the tutorial. In this explanation, Sara attempted to address one of the difficulties which was also a misconception that the learners had regarding the presence/absence of reactions at equilibrium. Four components were distinguishably and interactively used in this teaching strategy. First, the PPST begins with presenting *two different levels of representations* that talk to each other, to strengthen the explanation that follows. Explaining how the equilibrium state is reached during the change of state by water molecules, Sara explained one important concept that the forward reaction (evaporation of liquid water), does not go to completion before the reverse (condensation) begins (*evidence of curricular saliency*). This is an indication that in reversible reactions, there is both a forward and reverse reaction taking place within the chemical reaction. This removes the misconception that the reverse reactions only follow when all the reactants within a reaction are used up. This is evidence of learner prior knowledge. Highlighting (on the last point) what caused this kind of misconception then makes it possible for the teacher to select an appropriate representation to assist with making the concept more accessible to the learners (*evidence of what is difficult to comprehend*).

3.7.2. Analyzing for evidence of TSPCK in a teaching context

Researchers have argued that capturing and measuring PCK, and more specifically TSPCK in action is a challenging endeavor (Aydeniz & Kirbulut, 2014). On acknowledging the complexity of the construct's portrayal, Loughran et al. (2004) and Aydeniz and Kirbulut (2014) advocated the importance of developing and using praxis tools, to not only teach but also measure the teachers' PCK development. A validated rubric to evaluate TSPCK in teaching, in Table 3.4 (adapted from Miheso, 2018) was used in this study to analyze for evidence of TSPCK quality in action.

Table 3. 4: TSPCK rubric for scoring TSPCK in action (Miheso, 2018)

Type 1: Simple/Basic 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 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 TSPCK component interactions maybe interwoven or have a linear sequence structural formation or both • 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 interacting evidently and distinguishably in a specific teacher task segment Or • Evidence of four different TSPCK components interacting evidently and distinguishably in a specific teacher task segment, with one of the components repeated more than once or one of the components bringing different levels of sophistication (e.g. representations used at macro, symbolic and submicroscopic levels. • TSPCK component interactions maybe interwoven or have a linear sequence structural formation or both. • All the TSPCK components work together to support an explanation of a single or a pair of concepts that are related

The data collected from the actual classroom Chemical Equilibrium helped to answer the second research question in this study that reads - *What is the quality of the PGCE's TSPCK observed in classroom teaching and in what ways does it reflect the observed TSPCK in planning?* First, the lesson video records were transcribed verbatim. An in-depth qualitative analysis of ePCK (Park & Chen, 2012) was employed to analyze the lessons while applying TSPCK construct as the lens. The transcribed data was used to extract segments where two or more TSPCK components are evident and connectively used in an explanation and labeled as TSPCK episodes (Park & Chen, 2012; Miheso, 2018). The TSPCK episodes identified per PPST's lesson taught enabled their TSPCK episode profiles to be built for further analysis and interpretation. The episode could be highlighted (for example) through an explanation given by the PPST as they expound on a concept, using representations to explicitly emphasize what is important. Following this was an identification of the TSPCK components within the episodes identified and the sequence in which they emerged (Mavhunga, 2015). The episodes identified were presented in TSPCK Maps. The TSPCK Maps, as used in this chapter, are a way of visually representing the teaching episodes extracted from the teachers' lesson presentations. These Maps display pictorially, the sequence and the interactive manner in which components of TSPCK weave/intertwine in a teaching

segment (Mavhunga, 2015). The construction of TSPCK maps included drawing circular lines around each TSPCK component that was distinguishably interacting in a TSPCK episode. TSPCK components interacting in a linear sequence were represented with a solid linear arrow line which indicated the sequence in which the TSPCK components emerged in an episode. In cases where the TSPCK components were found to interweave, overlapping circles were used. For purposes of clarity, the components of TSPCK were abbreviated in the format used in Chapters 5 and 6: Learner Prior Knowledge, including misconceptions-(LPK), Curriculum Saliency-(CS), Representations-(R), what is difficult to teach and understand-(WD) and Conceptual Teaching Strategies denoted by (CTS). A shorthand TSPCK sequence was also used for ease of in-text citation to the sequence of TSPCK components displayed by the Maps (Mavhunga, 2018). The components that followed each other in a linear sequence were denoted by (-) while those following as interwoven format were represented using a forward slash (/). The quality of PPSTs' eTSPCK was described by the extent of an understanding of the interactive use of TSPCK components in explaining the content of a specific topic to the learners (Mavhunga, 2019). Based on the number of TSPCK components and the interplay between the components in an episode, a rubric presented in Table 3.2 was used to score the PPSTs' TSPCK in action into *basic, proficient or sophisticated TSPCK.* A TSPCK episode with only 2 different TSPCK components interacting, in either linear (WD-CS) or interwoven form (CS/WD) was categorized as basic. Where 3 different TSPCK components WD/R/CS or two components with one repeating (CS-R/CS), the episodes were categorized as proficient. Finally, TSPCK episodes with 4 different TSPCK components distinguishably interwoven (LPK/R/WD/CS) or with a combination sequence of linear and interwoven interactions (LPK/R/WD-CS) or 3components evidently interacting with one of the components repeating distinguishably (CS-R/LPK/CS) were categorized as sophisticated.

The chapter further drew on data from the PPSTs' lesson plans and stimulated recall interviews to corroborate the findings and thus enhance trustworthiness of the findings (Merriam & Tisdell, 2016). This inductive analysis was conducted to support the identified TSPCK episodes and pedagogical strategies employed by the PPSTs. The analysis was done by the researcher and two independent raters in the TSPCK field to ensure credibility of the analysis process. Any inconsistencies with the scoring were discussed until an agreement was reached. The inter-rater consistency of 0.92 was calculated which validated the identified TSPCK components and TSPCK

episodes in the PPSTs' lessons. An analysis of their enacted lessons was checked against their lesson plans for similarities. This also allowed for the study to explain how that which was planned translated into enactment, by comparing their TSPCK reflected in their lesson plans and TSPCK in action.

3.7.3. Analyzing for the link between the PPSTs' eTSPCK and learner outcomes

The purpose of every teaching activity is to impact positively on the learner performance. It is therefore arguably sound to say that what is reflected on learners' tests after being taught by a particular teacher could be considered as a mirror reflecting back the quality of the teacher who taught them. This is to say, although there are other factors that may affect learner understanding and interpretation of what is taught in the classroom (Gess-Newsome, 2015), how a learner responds to a question based on the teaching is also dependent on how the teacher explained it to the learners. An analysis of the learner outcomes included both the learner achievement and the learners' views about the PPSTs' teachings. Analyzing for the eTSPCK-learner outcomes link was done in three different stages. First, the analysis focused on establishing the learner achievement; the second focus was on establishing the correlation between the PPSTs' eTSPCK and learner achievement; thirdly, the learners' views about factors which possibly promoted or hindered their understanding of concepts covered by the PPSTs' teaching were examined.

Analysis of learner achievement

The test consisted of the items related to (i) the conditions leading to Chemical Equilibrium and (ii) the factors that affect the state of Chemical Equilibrium. They are the two Big Ideas in Chemical Equilibrium. First, a marking memorandum of correct answers was developed by the researcher and its correctness checked by two independent raters who are chemistry education specialists with an experience in science teacher education. The content test questions consisted of one correct answer and each item was scored a 0 and 1 for a wrong and correct response respectively (see Appendix D). Two additional chemistry specialists validated all the marked scripts to confirm the accuracy of the content and consistency of the marking. Any discrepancies that were found regarding the marking of scripts were then discussed until a consensus was reached. For the validation of the extent of agreement on the raw scores from the raters, the Kappa inter-rater consistency of 0.80 was obtained (McMillan & Schumacher, 2014). The raw scores

obtained from the marked tests were then quantitatively analyzed using the Rasch Winstep Software. The Rasch model converts the raw scores into probability measures on an equal interval scale (Boone, Staver & Yale, 2014). Thus, the raw scores are converted into linear measures, placed at an equidistant scale (Bond & Fox, 2015).

The Rasch model generates fit statistics, the IN. ZSTD and OUT.ZSTD statistical values which determines the validity of the measures. The fit statistical parameters measure the coherence of the responses of the persons to the level of difficulty of the items in the test. The fit statistical values for both item measures and person measures are considered as acceptable if they fall within the range of -2 and +2 which is considered a good match (Boone *et al*., 2014). This is an indication that the items and the person measures work together coherently, measuring a single construct, and thus constitutes a valid measure. For this study, the validity of the measures obtained was established within this acceptable range. Furthermore, the Rasch measures were anchored to test for any significant difference between learner pre- and post-test performances. This was done by fixing the Rasch measures of the items in the base test (pre-test) which was then used to anchor the post-test (Morrison & Fitzpatrick, 1992). The anchoring produced the 'stacked data' (Wright, 1996) with new Rasch Person measures accurate for comparison of learner performances in the pre-and post-test. Then, the stacked person data was subjected to the Wilcoxon Paired Signed-rank test (WPST) for non-parametric data in order to test for the significant difference if any, between the pre- and post-test performance scores of the learners. This test is considered suitable for use in the analysis of small sized samples; hence it is appropriate in this study.

Analysis of correlation between eTSPCK and learner achievement

The correlation analysis aimed to give an insight into the relationship between the PPSTs' eTSPCK and learner achievement in Chemical Equilibrium. First, the analysis only considered those test items from the learner-achievement tests which were covered by the PPSTs in their teachings. Fortunately for this study, all the test-items were covered in each of the PPSTs' teachings. The aim was to sift out the TSPCK episodes and minimize the noise of other factors which influence classroom enactment and learner outcomes. The correlation analysis began by using the rubric scores from the PPSTs' eTSPCK episodes and subjecting them to the Rasch statistical software called, Winsteps. The model converted the ordinal scores into quantitative linear measures (Boone *et al*., 2014). The PPSTs' Rasch person measures representing eTSPCK episodes and learners'

Rasch person measures from the analysis of learners' achievement tests were then run through the Statistical Package for the Social Sciences (SPSS) software (Aldrich, 2018) to calculate the Pearson correlation coefficient *(r)*. The correlation analysis that compares two variables requires paired data sets when running the statistical correlations (Greasley, 2007). Therefore, because of a different number of variables that were paired in this study, a strategic random sampling was done in three batches in order to allow for all variables to be paired (Lorenz *et al*., 2018; McMillan & Schumacher, 2014). As Lorenz et al. (2018) cautioned, each batch selected for further correlation analysis had to consist of data that was not included in the random selection of data for the previous batches to avoid bias.

By calculating the Pearson correlation coefficient (*r*), the study was able to establish the relationship describing both the strength and direction of the correlation between the PPSTs' eTSPCK and learner performances (McMillan & Schumacher, 2014). The strength of correlation describes the magnitude of the association between the variables while the direction refers to the signage of the association, which tells whether the association is positive or negative (McMillan & Schumacher, 2014). The guidelines provided by Hinkle, Wiersma and Jurs (2003) were used to interpret the strength and magnitude of a correlation coefficient in this study.

Table 3. 5: Guidelines for interpreting the size of correlation coefficient (Hinkle et al., 2003)

Range of *r* (+ or -)	**Interpretation**
0.90 to 1.00	Very high correlation
0.70 to 0.90	High correlation
0.50 to 0.70	Moderate correlation
0.30 to 0.50	Low correlation
0.00 to 0.30	Negligible correlation

Stronger linear relationships are explained between variables whose correlation coefficients are closer to -1 or +1. A positive correlation exists when variables are directly associated whereby as the value of one variable increases, so does the value of another variable (Schober, Boer, & Schwarte, 2018). A negative correlation coefficient on the other hand reveals an inverse association between variables whereby as the value of one variable increases, a decrease occurs in the value of another variable (Schober *et al.,* 2018). The correlation coefficient of zero however, implies that there is no linear association between two variables being compared (McMillan & Schumacher, 2014; Schober *et al.*,2018).

An in-depth qualitative analysis then followed where the actual learners' performances on each test item were matched with the corresponding explanation given by the PPST in the actual classroom teaching. This matching was essential, especially when the examined PCK and its associate TSPCK is situated in the actual classroom and hence the quality of TSPCK can be observed from the explanations provided by the PPSTs (Park & Chen, 2012; Park & Suh, 2019). Furthermore, the qualitative analysis explained qualitatively, the weakness or strength of component interactions in TSPCK episodes from the established strength of correlation between the PPSTs' eTSPCK and learner achievement. Two raters who are TSPCK researchers assisted with confirmation of the overall TSPCK episodes, strategic random selection when pairing variables and in identifying specific TSPCK episodes that matched the test items. The confirmation of the processes of leading to correlation analysis was done to ensure reliability of the correlation results.

It is worth noting that due to the absence of the control group, the correlation analysis does not in any way attempt to claim that the improvement in learner performance was caused by the quality of the PPSTs' TSPCK. Rather, the analysis helped to explain the possible relationship between the two variables.

Analysis of learners' views

The learners' written responses to the items which asked for their views were used to corroborate the findings during the qualitative analysis of the correlation between PPSTs' eTSPCK and learner performances. As it has been alluded to above, a qualitative analysis for correlation involved matching learner item responses to the corresponding explanations provided by each PPST. In support of this, the learners' views regarding what contributed to or hindered their understanding of concepts was used to emphasize the established TSPCK-learner outcome link.

The use of mixed methods research design in this study enabled an in-depth exploration of the TSPCK-learner outcomes link through the cPCK-plPCK-ePCK trajectory while learning to teach Chemical Equilibrium. As a result, the convergence of the qualitative and quantitative methods was considered appropriate.

SUMMARY OF THE RESEARCH DESIGN

Table 3. 6: Summary of the Research Design

Research Question	Data sources	Data Analysis
1. What is the quality of TSPCK displayed by the PGCE pre-service teachers in their planning for teaching Chemical Equilibrium, following the explicit discussions of the intervention that aimed at developing their knowledge for planning to teach Chemical Equilibrium?	➢ Completed pre- and post-TSPCK tests in the topic of intervention, ➢ Tutorial presentations during the intervention, ➢ Post intervention CoRes.	➢ PGCE student teachers' pre-and post TSPCK tests in the topic of intervention were analyzed using a planned TSPCK rubric and compared. Three raters who are familiar with a TSPCK construct were asked to independently score the TSPCK tests. ➢ This analysis was complemented and therefore triangulated with analysis of the CoRes and tutorial discussions tasks.
2. What is the quality of the PGCE's TSPCK observed in classroom teaching and in what ways is does it reflect the observed TSPCK in planning?	➢ Audio/video recorded lesson observations, ➢ Thick observation notes, ➢ Stimulated recall interviews.	➢ The video recorded lesson observations transcribed verbatim, followed by data coding by identifying TSPCK episodes during their lesson delivery. ➢ Comparative content analysis using qualitative in-depth analysis: Identification of TSPCK Episodes; identification of TSPCK components present, description of their sequence and the manner they are used interactively. Three raters, familiar with TSPCK were asked to independently perform a comparative content analysis of this data
3. In what ways does the observed PGCE's enacted TSPCK observed in the classroom relate to learner performances in Chemical Equilibrium?	➢ Completed TSPCK tests in the topic of intervention, ➢ Completed post CoRes on the topic of intervention, ➢ Content of tutorials during the intervention, ➢ Video recorded lessons, ➢ Lesson plans, ➢ Learner achievement tests and views on PPSTs' PCK, ➢ Stimulated recall interviews.	➢ Quantitative and qualitative analysis of learner achievement. ➢ Statistical correlation analysis between the PPSTs' eTSPCK and learner-achievement. ➢ In-depth qualitative analysis of actual learners' performances on each test item matched with the corresponding explanation given by the PPST in the actual classroom teaching

3.8. Trustworthiness and Validity

Garuth (2013) contends that validation of the mixed methods approach involves the evaluation of the quality of the findings. The quality of the findings in mixed methods approaches should be evaluated from both qualitative and quantitative strands (Garuth, 2013). These are discussed below.

3.8.1. Qualitative method

An important consideration in qualitative paradigm is the credibility and trustworthiness of the research (Shenton, 2004; Wagner et al., 2012; Cope, 2014). Merriam (1995) argues that on the basis of trustworthiness lies the question of the ability of the research to do exactly what it has been designed to do. Shenton (2004) and Cope (2014) discussed the four ways in which the

trustworthiness of a qualitative research can be confirmed, as identified by Guba (1981). These ways include credibility (in preference to internal validity), transferability (in preference to external validity/generalizability), dependability (in preference to reliability), and confirmability (in preference to objectivity). Credibility refers to the congruency of the research findings regarding the reality and transferability referring to the extent of applicability of the findings to other situations and populations. Dependability, on the other hand, is concerned with the "methodological description" that is given that allows for the repeatability of the study while confirmability ensures that the "work's findings are as a result of the experiences and ideas of the informants rather than the characteristics and preference of the research" (Shenton, 2004:72). Reliability refers to the consistency and dependability of the research tools used in the data collection (Leedy & Ormrod, 2005; Wagner *et al.,* 2012; Noble & Smith, 2015). The source of data collection is said to be reliable if the same result can be obtained repeatedly when using similar research tools (Leedy & Ormrod, 2005; Wagner *et al.,* 2012).

To ensure the trustworthiness and dependability of the results, multiple data collection tools were used for triangulation. This was to ensure consistency in the results obtained through gaining an articulate, comprehensive view of the phenomenon being investigated (Cope, 2014). As postulated in Merriam (1995), triangulation involves "the use of multiple investigators, multiple sources of data, multiple methods to confirm emerging findings" …such that, "if the researcher hears about the phenomenon in interviews, sees it taking place in observations, …he or she can be confident that the "reality" of the situation, as perceived by those in it, is being conveyed as "truthfully" as possible" (p.54). In using multiple data collection techniques, the study ensured that the research findings are credible and authentic (Wagner *et al.,* 2012). All the lessons observed, and interviews were audio/video recorded, also ensuring the trustworthiness and providing evidence that the collected data is reliable.

Research findings and interpretations were also reviewed and critiqued by the qualified researchers in the field, and three independent raters, to help reach the consensus, with the aim to ascertain credibility and reliability of the findings. This included the scoring of the TSPCK tools and learner achievement tests. Each rater was given an unmarked copy of the test to mark independently. The scores were later compared and score differences confronted, discussed and consensus reached on the score settlement. The raters and qualified researchers, who are specialists in the field, assisted

with the identification of TSPCK episodes from lesson observations as well as data coding and scoring using the TSPCK rubrics. To ensure reliability, a researcher provided a thick description of the intervention in chapter 4, thus giving clarity on how the intervention was done, so that it could be used by other researchers who are interested in a similar range of research. Providing a thick description of the intervention ensured the replicability of the findings by other researchers (Nowell, Norris, White, & Moules, 2017). A "Thick description involves providing enough information/description of a phenomenon under the study so that the readers will be able to determine how closely their situations match the research situation, and hence, whether findings can be transferred" (Merriam, 1995, p. 57).

For data confirmability, the researcher performed follow-up interviews with the PPSTs. This enabled the PPSTs to explain and give clarity to some occurrences in the classroom regarding what they had presented in their lesson plans (Asan & Montague, 2014). According to Merriam (1995: 52), doing member checks by "taking data collected from the study participants and tentative interpretations of these data, back to the people from whom they were derived and asking if the interpretations are plausible, if they "ring true"" is an especially important technique of ensuring data validity. Verifying the research findings and interpretations with the participants also acts to enhance data credibility (Cope, 2014). Data confirmability was also exhibited during the analysis by providing rich quotes from the participants' captured data (Cope, 2014; Nowell *et al.*, 2017). This was done with the purpose of ensuring that the interpretations and conclusions made are derived from the data captured from the participants and not the researcher's own viewpoints and biases (Cope, 2014; Nowell *et al.*, 2017).

To prevent or to reduce the external or internal influences as the researcher, I tried as much as I could to remain objective and neutral in collecting and analyzing the data. Even though the researcher was present in the intervention, participation did not affect the judgement made at all, especially in collecting the necessary data for this study. Taking thick notes during the intervention also helped to reduce any bias that might have been caused by the researcher's participation in the intervention during the data collection process and interpretation. As part of the notes that the researcher took, pictures of any representations used during the intervention sessions were also taken, to capture some of the classroom occurrences that might not be easy to capture through

audio recordings. This added to the authenticity of the descriptions (Opie, 2009) of the intervention and assisted with the data analysis and interpretation made.

3.8.2. Quantitative method

Two validation measures, validity and reliability of research are adhered to in quantitative research (Venkatesh *et al.,* 2013). Validity refers to the degree in which the research measures what it is supposed to measure (Venkatesh *et al.,* 2013; Heale & Twycross, 2015). Reliability, on the other hand, refers to the extent to which a method/instrument gives constant or similar results (Opie, 2009; Venkatesh *et al.,* 2013; Heale & Twycross, 2015). The content questions on the tests were extracted from the valid National Examination Papers. This ensured that the test was valid and at the level of the learners that it was developed for. All the tools adopted in this study were used in the previous studies with similar contexts and participants to ensure their reliability and validity. Independent raters were involved in marking the responses for all the administered tools to ensure accuracy of the data collected. Furthermore, a Rasch statistical analysis was used in this study to ensure validity. The statistical measures such as the person ability and item difficulty helped to establish the validity and reliability of the measures, where valid measures ensure that all the items jointly work to measure a single construct and that the level of difficulty of the items is determined (Boone *et al*., 2014). Ultimately this links to the statistical fit that is deemed to be acceptable if it falls between the fit values of -2 and +2. This shows the validity of the measured construct (Boone *et al*., 2014).

3.9. Limitations

One of the limitations evident in this study is the sample size which is quite small (eight PPSTs). The limitation is further enhanced by the use of an even smaller sample of PPSTs for lesson observations when exploring the translation of plTSPCK into classroom enactment (eTSPCK). For the majority of the PPSTs (five in total), only their espoused TSPCK was captured from their TSPCK tests, CoRes and tutorials, which limited the description of the PPSTs' eTSPCK to a minority of three participants. The second limitation could be the researcher's inexperience with data analysis, which may have created some bias during the analysis. To reduce this bias, the researcher sought assistance from independent raters to not only look at the video/audio records but to also assist with data scoring and interpretations.

3.10. Ethical Considerations

Consideration of ethical issues becomes morally important when the research involves collecting data about people and from people (Punch, 2009). Obtaining *informed consent* from people becomes a requirement. Before any data was collected, the ethical clearance was sought from the Ethics Committee at the university where the study was based. Consent forms (see Appendix M) were then given to the PPSTs to show their willingness to participate in this study. The forms explained the purpose of the research study, its benefits, the confidentiality and anonymity of the data collected. Before signing, the PPST received an explanation and assurance on the issue of confidentiality. Assurance of confidentiality was given explicitly concerning the audio and video recordings to protect their privacy as participants. Pseudonyms were assumed throughout the study in place of the real names as a way of preserving the participants' true identity to great anonymity. Consent was further sought from the Head of school at the University where the study was based (see Appendix J). The physical science methodology course coordinator (see Appendix K) and the course lecturer (see Appendix L) were also consulted. The approval was obtained from the Gauteng Department of Education (GDE) to conduct research in some schools around the Gauteng province and more specifically those within central Johannesburg (see Appendix I). Thereafter, permission was sought from the schools where the PPSTs were placed for TE to have them teach chemical equilibrium to grade 12 learners. This was done before the PPSTs went to the schools on TE. Out of eight schools from which the motivation to participate in this research was done: only three consented. As a result, the researcher asked three PPSTs to follow into TE, where their lessons were video recorded. This was also voluntary. It is important to note therefore, the selection and choice of PPSTs to follow up with the actual classroom teaching was also determined by an agreement and willingness of the schools and subject teachers to participate. Consent from schools was obtained from all the stakeholders involved. These included the school principals (see Appendix N), physical science teachers (see Appendix O), learners (see Appendix Q) and parents of the participant learners below 18 years of age (see Appendix P). The consent forms stated that participation was voluntary hence any participant was free to withdraw at any stage without fear of ridicule.

CHAPTER 4

THE TSPCK BASED INTERVENTION WITH THE PGCE PRE-SERVICE TEACHERS

In this chapter I provide a thick description of the intervention treatment conducted with the PPSTs in a physical science methodology course, the chemistry section of the module. This intervention sought to develop the pre-service teachers' Topic Specific Pedagogical Content Knowledge (TSPCK) on a specific chemistry topic of chemical equilibrium. At the core of the intervention discussions was the interactive use of the components of content knowledge transformation in planning to teach and in the teaching of Chemical Equilibrium. This chapter begins with an explicit discussion of the content-specific components of TSPCK with the PPSTs, followed by a description of a CoRe and its significant use in this intervention.

4.0. Introduction

South African teacher training institutions that offer a degree, prepare teachers through two main streams, a 4-year B. Ed. degree and PGCE stream that undergo a one-year full-time programme (Mavhunga& Rollnick, 2017). Unlike the B. Ed. students whose curriculum is organized around 4 years of content and methodology aspects of teaching, including learning theories and pedagogical reasoning skill as well as teaching practice, the PPSTs are only prepared to teach without much attention on the content of that subject because of the assumption that they had all the necessary content that they would need in their teaching (Hirst, 1980; Ogunniyi and Rollnick, 2015). A one-year full-time PGCE programme was preceded by a general bachelor's degree that included studying the subject matter in the discipline of interest. Therefore, for PPSTs, the curriculum that the B. Ed. students do in four years is compressed to be done within a year, with an exclusion of subject matter knowledge (Taylor, 2014). The PPSTs are then prepared to teach without much attention to the content of that subject (Hirst, 1980; Bayaga, 2010). Of particular interest in this study is the impact of the methodology course which targeted the development of the PPSTs' TSPCK for teaching the science topics.

4.1. Explaining the rationale for conducting the intervention

The intervention happened in a PGCE chemistry methodology or methods course which provides the PPSTs with pedagogical knowledge for teaching the subject matter (Witzig & Zickel, 2017). All the methodology courses in the Science Education division at the institution where this study

was conducted are driven by the common objective to "develop a specific depth and specialization of knowledge, together with practical skills that comprise a professional teacher competence for teaching core topics in a specified science discipline…" (Mavhunga& Rollnick, 2017, p. 152). The methodology courses at this university employ the PCK construct, more specifically TSPCK, as a framework in developing the traditional B. Ed. PSTs' pedagogical knowledge. The construct is used for its benefits to afford teachers a framework through which to transform difficult content knowledge for accessibility by the learners. At the institution where this study was conducted, the B. Ed's. methodology courses are offered concurrently with the content courses, thus affording the benefit to PSTs to learn content knowledge of a specific topic and the knowledge for teaching it at about the same time (Mavhunga & Rollnick, 2017). It has been argued that the parallel model of offering teacher education, allows the PSTs to develop a culture related to the profession (Nyamupangedengu, 2016). The key rationale for the division of Science Education to focus on TSPCK vs. the broader PCK construct is that it distinctively focusses on teaching and developing PCK in one science topic at a time, thus bring to the fore the content-specificity of the PCK being developed. Studies that have explored the use of the TSPCK construct, together with other approaches that employ content-specific tools, such as Content Representations (CoRe), have been noted for the success that they registered in enabling improvement in the quality of PSTs' PCK in a specified topic (Nilsson & Loughran, 2012). Furthermore, it has been shown that PSTs exposed to such content specific focus on PCK in the science education division, develop a competency to apply the acquired knowledge and 'know how' to self-develop PCK in new science topics (Mavhunga, 2016).

Following visible success in the implementation of TSPCK in the B. Ed. stream methodology courses, the framework was extended to the science PGCE programmes (from 2017), which are mainly methodology courses. As it is mentioned above, the PPSTs' programme focus is mainly on the pedagogy of teaching and very little on the subject matter knowledge. The reason is that they are a group of graduates whose programmes are assumed to have equipped them with the necessary knowledge in the disciplines that they wish to teach. In the four years of B. Ed., PSTs are exposed to the construct at least for a total of 6 weeks in each academic year, thus on completion of their studies, the PSTs would have been exposed to the TSPCK discussions with different topics multiple times. The same intervention, however, ran for six weeks only for the PPSTs because of the nature of their programme being a 1-year full-time course. The purpose of

this study therefore is to examine the impact of the intervention on how the PPSTs develop their personal TSPCK evident in their competence to transform their existing content knowledge into forms that are more understandable to the learners. Although a reasonable number of researchers attests to the improvement in teacher knowledge by the PSTs after an exposure to the intervention (Mavhunga, 2014) little is known about the impact of the same intervention on the PPSTs. While the intervention and its findings may not be a new encounter, its findings in this study will act as a baseline for examining the quality of the PPSTs TSPCK in downstream teacher tasks such as in action when teaching chemical equilibrium concepts, and how this links to learner achievement.

4.2. Describing the structure/outline of the intervention

The intervention occurred over a period of 6 weeks, constituting an overall twelve sessions of three hours per week. The three hours were divided into two sessions, each constituting one-and-a-half hours. The first session was scheduled at the beginning of the week and the second towards the end of the week. Sessions at the beginning of the week introduced and explicitly discussed individual TSPCK components, including how they can be used to transform Chemical Equilibrium concepts. The second session of the week was used for tutorial presentations by the PPSTs revealing their understanding of the components and how they can use these in transforming content knowledge on chemical equilibrium. The classes were presented by the researcher with the support of an experienced teacher educator. The class was divided into four permanent groups of two PPSTs each, which were maintained throughout the entire period of the intervention. The pairs worked together every week in preparation for the tutorial presentations.

The content of the intervention focused on introducing the components of TSPCK one at a time, reasoning through the topic for each component perspective. While the intervention discussions dealt with one component at a time, the participants were made aware of the interactive and connectedness in the use of the TSPCK components when transforming content knowledge. These moments were always evident in that other components popped up even before they were discussed. Through use of this framework of content knowledge transformation, the PPSTs were expected to develop competency to reason through their content and plan to teach for understanding. The result of the application of this framework on the subject content is the

transformed content knowledge that learners can easily comprehend. Table 4.1 gives an overview of the intervention sessions' content and activities.

Table 4. 1: Content and structure of the intervention in a Chemistry methodology course

Scheduled time	Activity	Content of the activity
Week 1	1. A pre-intervention TSPCK test, 2. Lesson planning 3. Reviewing of the chemical equilibrium content, 4. **Learner prior knowledge including misconceptions.	• Administration of the pre-intervention TSPCK test on chemical equilibrium, • The structure of a lesson plan: Introduction, body/presentation and conclusion, • Chemical equilibrium concepts: Mass actions, Nature of chemical equilibrium, reversibility of chemical reactions, graphs, and equilibrium constant versus equilibrium quotient, • Introduction of a TSPCK framework of content knowledge transformation: conceptions and common learner misconceptions on chemical equilibrium found in the literature, including strategies to use to confront such misconceptions.
Week 2	1. **Introducing curriculum saliency	• Aspects of chemical equilibrium considered as peripheral and core to the understanding of the topic, • Topic restructuring as per the CAPs document, • Using concept maps to arrange main and subordinate concepts of a main topic, • Big Ideas formulation from the main concepts of the topic presented in the order/sequence in which they are taught.
Week 3	1. **What is difficult to understand	• Identification of gate-keeping concepts contributing to the difficulty of specific chemical equilibrium concepts.
Week 4	1. **Use of representations	• Use of multiple forms of representations; microscopic, sub-macroscopic and symbolic representations to concepts are explained, • Developing competency to choose and use representations that support understanding of abstract and difficult concepts.
Week 5	1. **Conceptual teaching strategies, 2. **Bringing all components together.	• A specifically designed strategies of teaching important concepts within a topic, learner difficult concepts, as well as specific learner misconceptions, • Bringing in all components together to stress the importance of an interactive use of components when explaining concepts.
Week 6	1. **Introduction of a CoRe, 2. An assignment issued on CoRe and TSPCK test.	• A CoRe explained as an instrument that brings together all components of content knowledge transformation with the purpose of capturing the teachers' knowledge and understanding of subject matter knowledge, • The two assignments (post-intervention CoRe and TSPCK tests) were issued on the last week of the intervention. The CoRe submission date was scheduled for two weeks after the intervention, whilst the TSPCK- test was to be submitted a week after the intervention.

A detailed description of the intervention is provided below. The activities marked with the asterisks above signify the actual components of the TSPCK framework that were explicitly discussed in the intervention. The first few activities were meant to create a foundational knowledge base (for all pre-service teachers) from which the intervention was focused to create a common understanding of the topic. It also provided an easy and natural flow into the discussions that followed on the content knowledge components. This correlates with the understanding in the literature that, knowledge of the subject content is necessary for the development of knowledge for teaching (Pitjeng-Mosabala & Rollnick, 2018; Neumann, Kind, & Harms, 2019). It was because of this understanding that the concepts of Chemical Equilibrium were discussed prior to the discussion of the components of TSPCK that enable the content knowledge transformation.

4.2.1. The intervention sessions – Introduction session

The first session introduced the group to lesson planning. A lesson was observed to have three parts, the introduction, the presentation (lesson body) and the summary of the lesson. The importance of planning for the lesson prior to teaching was emphasized as helping the teacher to arrange the content in a sequence that learners can efficiently understand. Reference was made on the importance of using or incorporating the teaching and learning theories in one's planning and teaching. The highlighted theories were *learning through inquiry, argumentation, scientific method or transformation of content.* More specific emphasis was put on the theory of *content knowledge transformation*, the main theory through which the intervention discussions would be focused throughout the six weeks' period. At this moment, the PPSTs were introduced to the TSPCK construct as consisting of five components of content knowledge transformation. Knowing which theory of teaching/learning to use at a particular point in time was underlined as essential in assisting the teacher to focus and efficiently structure their planning to meet the objectives of the lesson. Emphasis was made on the topic specific nature of the PCK construct that the intervention would be based on. This was referred to as topic specific PCK (TSPCK) because it involved transformation content knowledge specific to the topic: Chemical Equilibrium. It was further mentioned that the main interest of the intervention was to help PPSTs develop the ability to transform their content into versions that learners can efficiently comprehend (Mavhunga & Rollnick, 2017). The five content-specific components of knowledge transformation listed are *learner prior knowledge including misconceptions, curricular saliency, what is perceived as*

difficult to understand, the use of representations and analogies as well as conceptual teaching strategies. TSPCK helps one to deal not only with the content, but also with how to teach the content. It enables one to study the content in depth from the perspective of the learners and understand it more meaningfully. The group was also made to understand that even though the discussions were based on a topic of chemical equilibrium, the same construct and way of thinking can be used to transform the content for planning and teaching of other topics.

4.2.2. Learner prior knowledge including misconceptions

The discussion of the TSPCK framework commenced with a component of Learner Prior Knowledge (LPK) introduced from a perspective of common learner misconceptions (CLMs). The discussion was focused on developing an eye for the consideration of the LPK in planning and teaching for understanding. It pointed out that the effect that the lack of consideration of LPK can have on learner understanding. LPK was described as the knowledge that the learner brings into the classroom that could contribute to the development of teaching strategies that are cognizant of such misconceptions and therefore prevent them from happening. As discussed in Kurnaz and Sağlam-Arslan (2011) constructivism suggests that "learning happens when new knowledge is connected to existing knowledge" (p. 51). LPK was also referred to as learner conceptions on correct knowledge or alternative conceptions in relation to the current topic. For example, learners may have a doubt on a specific concept which is not necessarily incorrect but because they do not fully understand it. Misconceptions which are also known as alternative conceptions were then referred to as inaccurate/inappropriate content that learners hold regarding a certain topic (Kambouri, 2016). These are conceptions that do not relate to scientific definitions (Kurnaz and Sağlam-Arslan, 2011). An example could be the learners' thinking that at chemical equilibrium, the concentrations of reactants and products are equal. Overall, misconceptions were referred to as incorrect knowledge or correct knowledge with a doubt or uncertainty.

LPK, including misconceptions, was referred to as one way in which content can be looked into to help improve learner understanding of the current topic. The idea of identifying learner misconceptions before teaching a topic was explicitly emphasized as important so that they are dealt with and corrected beforehand when a new topic is discussed. A teacher then understands what learners are struggling with within the topic and identifies ways of addressing those problems in their teaching. Gottheiner and Siegel (2012) discuss the fact that "addressing students' prior

knowledge helps foster learning" (p. 532). Their consideration was said to enable the teacher to devise teaching methods that build conceptual bridges between what is familiar and what is new, using simple and clear visualization of abstract concepts, which enable a better acquisition of scientific concepts (Magnusson *et al.*, 1999). Further, PPSTs were told to always consider the sources of the misconceptions as this may give them the capacity to understand what needs to be done to clarify or correct those misconceptions.

(a) Investigating common learner misconceptions on chemical equilibrium concepts

The PPSTs were provided with an article that explored some of the CLMs in Chemical Equilibrium by Pekmez (2010). Each group was provided with two misconceptions extracted from the article to work on in teams. The participants were asked to familiarize themselves with the CLMs enlisted in the article and identify the possible reasons behind the misconceptions as well as the pre-concepts needed or lacking that resulted in those misconceptions. They were asked to prepare slide presentations for the tutorial session where each team would make a presentation on its given misconceptions and have feedback from the class. Given below are the responses of the PPSTs to common learner misconceptions as extracted from the article.

Extract 1: "***No reaction occurs at equilibrium"***

One of the CLMs in Chemical Equilibrium identified in the literature is that there is no reaction happening at an equilibrium state (Pekmez, 2010). The response in Figure 4.1 by Jane's group was presented during the tutorial session.

A response by Sara and Jane

Reason for misconception:

- No Macroscopic changes
  - No visible changes,
  - No overall concentrations change.

Pre-concepts required for understanding:

Microscopic properties.



Figure 4. 1: Sara and Jane's response on common learner misconceptions

According to Sara and Jane, this misconception could possibly result from the inability of the learners to visually see any movement of chemicals at a macroscopic level. They linked this to the understanding about constant nature of the concentrations of reactants and products at an equilibrium state and the equal rates of forward and reverse reactions which are often interpreted as implying no reaction happening. It was then argued that the use of microscopic level representations would play an important role in showing the learners that there are reactions happening at an equilibrium position. The emphasis at this point was that teachers need to use diagrams or representations that may enhance learner understanding and minimize development of alternative conceptions.

Extract 2: ***"If the amount of a reactant is increased, its concentration remains the same"***

The second CLM is that an increase in the amount of a reactant to a reaction that has reached a state of chemical equilibrium does not affect its concentration (Pekmez, 2010). The response below was provided by Daniel and Mandla on the ***reasons that might have resulted in this misconception*** as well as ***the pre-concepts required for learner understanding of the concept.***

Possible Reasons for the misconception: The group argued that the word "Amount" is vaguely used. They raised some questions and interpretations about the word "amount".

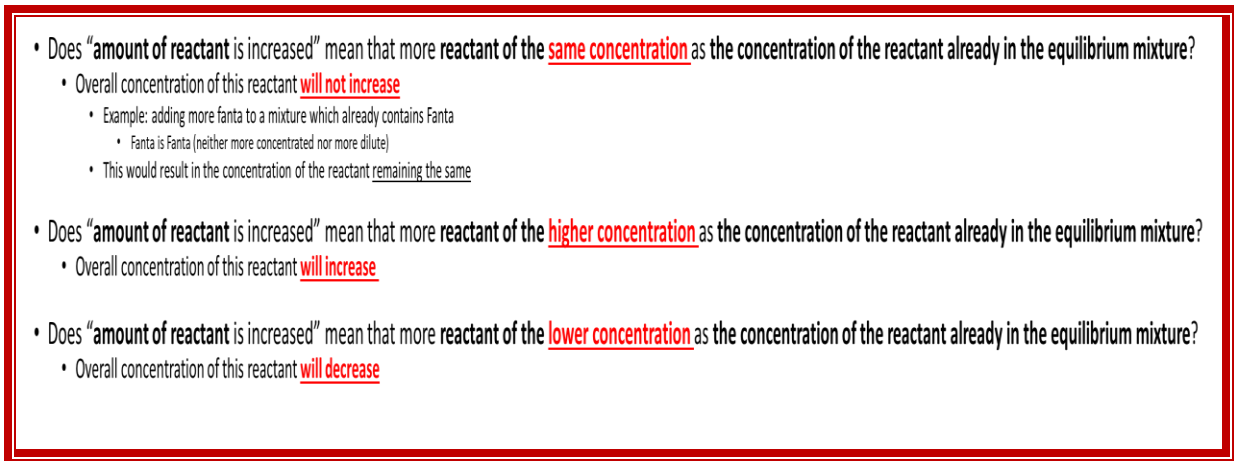


Figure 4. 2: Daniel and Mandla's misconception interpretation

The group anticipated the word amount as potentially problematic to the learners. The confusion caused using the terms "amount and concentrations" on learner understanding of chemical equilibrium concepts has been documented in Bergquist and Heikkinen, (1990) where it was emphasized that teachers should always explain the terms used in their teaching. This would be to

ensure that the meaning and understanding of concepts is not lost only because the learners cannot understand the context in which a term is being used. The PPSTs were made aware that the way teachers themselves teach concepts of chemical equilibrium could lead to the development of those misconceptions (Bilgin, Uzuntiryaki & Geban 2003), hence the need to devise teaching strategies that can lessen their development. Discussed below are the pre-concepts that the group presented that learners could be missing for the understanding of this content.

Pre-concepts missing for the understanding of content: The group pointed out that a learner with this misconception may not have a thorough understanding of amount / moles / concentration; thus, the learner might not relate the increase in amount n=m/M to concentration c= n/V. The group's ability to recognize the pre-concept important in the understanding of the highlighted terms "moles versus concentration" provided a sense that they understood the concept better and hence could easily find a way to eliminate this misconception in their teaching. However, based on the interpretations that the group provided in Figure 4.2 above, it was clear that they were also confused by the terms. This confusion initiated a discussion that aimed at explaining the two terms.

What the PPSTs needed to understand from this was that the term amount is referred to in terms of moles of a substance per the constant volume of a reaction system. The fact that this reaction occurs in a closed system implies that the volume of the system is kept constant. This suggests that the amount of that reactant in the system of a specified volume increases the overall concentration of the added reactant as demonstrated in the equation $concentration = \frac{moles}{volume}$ that concentration is directly proportional to the number of moles.

In exploring the CLMs, given what I saw, the PPSTs had a chance to explore even their own misconceptions and got corrected from the class discussions.

4.2.3. Curricular Saliency sessions

The discussions on curricular saliency (CS) were intended to help the pre-service teachers to learn about Chemical Equilibrium subject content relative to the curriculum as a whole (Geddis & Wood, 1997). CS was referred to as the learning of various topics as positioned in the curriculum (Rollnick *et al.*, 2008; Mavhunga, 2012). It involves knowing the most important meaning that must be established; including what is core and peripheral to the topic. As Mavhunga and Rollnick

(2017) explain, CS encompasses "knowledge that assists in developing a structural overview of a topic" (p.159). Four main features were referred to as important in assisting to unpack the structure of the topic, such as: *(i) Identifying the most important meanings, without which the understanding of the whole concept will be missed; referred to as Big Ideas*; *(ii) Knowledge and understanding of immediate/ pre-concepts needed before learners are exposed to new knowledge*; *(iii) Subordinate concepts* and *(iv) Sequencing of the concepts in the order in which one intends teaching them*. Identification of immediate concepts was underlined valuable in helping the learners to understand new concepts. For example, for the learners to understand the concept of chemical equilibrium and the nature of the overall reactions at an equilibrium position, it is imperative that they are first introduced to "chemical reactions" and "collision theory" amongst other topics. The steps below were followed to further explain the component of CS to the PPSTs.

a) Formulating Big Ideas

To help in this regard, the idea of concept maps was introduced. This involves breaking the topic into usable forms and pillars that make it up and that are placed in a sequence in which the teacher will discuss. Construction of concept maps followed the following sequence: identification of main concepts, formulation of Big Ideas from main concepts and identification of subordinate concepts. The main concepts were referred to as important things to understand about the topic, without which the topic cannot be understood. These were placed within a concept map from which Big Ideas were formulated. The Big Ideas referred to meaningful statements that describe the main concepts to develop the learners' understanding of the topic. Identification of subordinate concepts followed below each main concept within the concept map. Accordingly, all these concepts must be written in a sequence that brings about the most pedagogical and logical coherence in teaching.

Formulated from each main concept are big ideas which were referred to as complete statements about the correct understanding of main concepts in a topic. They were further explained as written statements about the meaning of concepts that are core to the topic. Loughran and his colleagues refer to the importance of identifying Big Ideas as valuable in enabling the teachers to present how they frame and conceptualize the topic; "an important aspect of articulating one's PCK" (Loughran *et al.,* 2004:379).

b) Construction of concept maps by the PPSTs

The PPSTs were given a tutorial task to construct their own concept maps using their knowledge and own interpretation and understanding from the session and a CAPs document for reference. The maps had to include main concepts and subordinate concepts that make up the topic chemical equilibrium. They were also requested to construct Big Ideas corresponding to their suggested main concepts. Figure 4.3 displays the responses from two teams: Daniel and Mandla, as well as Lerato and Noma.

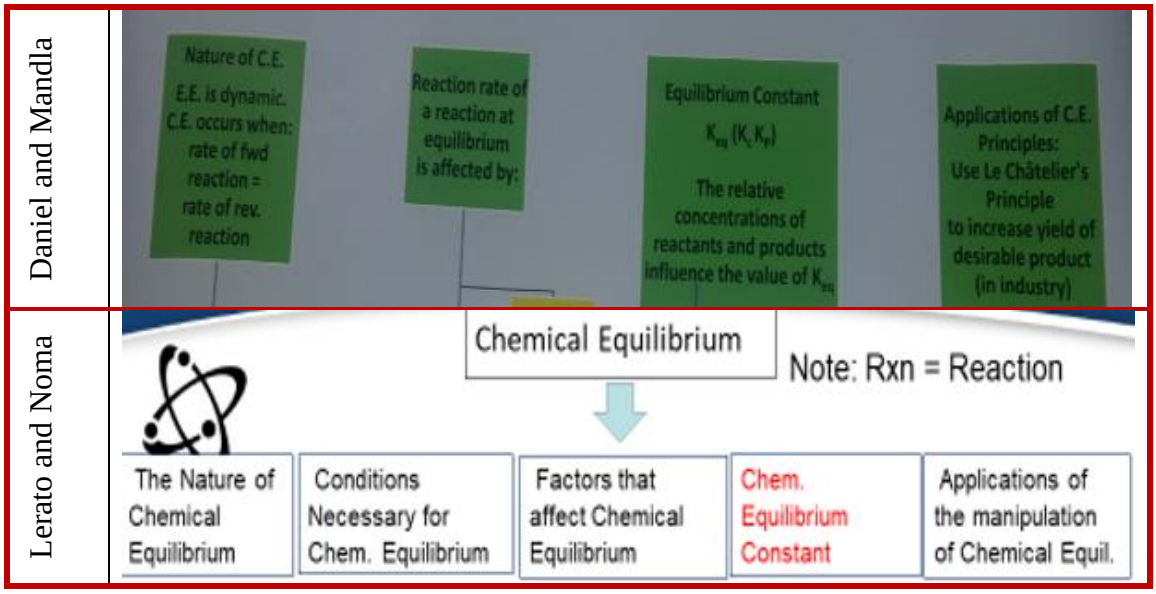


Figure 4. 3: PGCE Pre-service teacher responses on a component of curricular saliency

To summarize this component, between four and five main concepts were identified: (i) the dynamic nature, (ii) Conditions for chemical equilibrium, (iii) Factors that disturb chemical equilibrium, (iv) Determination of chemical equilibrium, (v) their applications. All groups appropriately identified corresponding subordinate concepts for each main concept that they presented. Only two groups, Jane's and Daniel's constructed Big Ideas for each main concept that they identified whilst 2 other groups did not. The members of these two groups (that did not construct the Big Ideas) argued that they did have a clear distinction between "main concepts" and "Big Ideas" of a topic. The distinction between main concepts and Big Ideas was made explicit whereby main concepts were described as core/key concepts of the topic while Big Ideas are meaningful statements that describe those core concepts required in developing the learners' understanding of the topic. For example, for a main concept such as *"conditions for chemical*

equilibrium", a statement such as *"chemical equilibrium happens only in closed systems where temperature and pressure are kept constant*" was given as an example of a Big Idea statement providing meaning to the concept given.

Individual PPST task during the tutorial: After the group presentations in the tutorial, the PPSTs were provided with a page long content on chemical equilibrium concepts. They were asked to use the given content to construct at least 2 big ideas. A great improvement was observed in their responses where most were then able to present Big Ideas to the topic.

4.2.4. What is difficult to understand and teach?

Chemical Equilibrium has been classified as one of the topics that are abstract in nature. It is not easy to understand and teach and requires the use of specific content and terminologies (Mavhunga & Rollnick 2013; Pekmez, 2010). The authors further argue that, "the meaning of the phrase 'equilibrium' is different from the daily use of the term. For example, an everyday meaning of equilibrium, extracted from the dictionary is "a state of rest or balance due to the equal action of opposing forces" while in chemistry, a state of equilibrium is referred to as a condition within a chemical reaction in which both a forward and reverse reactions occur at the same rate and the concentrations for both reactants and products remain constant/unchanged. Further difficulties are reported for the understanding of the constant nature of the equilibrium constant (Van Driel & Graber, 2002), and the "unequal concentrations of reagents at equilibrium" (Mavhunga and Rollnick, 2013, p. 114).

The session explored the concepts that are not easily understood by the learners and which require teachers' critical emphasis and attention. These were described as gate keeping concepts to the topic of chemical equilibrium that contribute to the difficult nature of the topic; this also makes it difficult for teachers to teach them (Huddle *et al.,* 2000; Quilez-Pardo, 1995). It was made explicit in the discussion that some of those difficult concepts could end up creating learner misconceptions if teachers do not find ways of transforming them to enhance their accessibility and comprehension by the learners, usually reinforced by the kinds of analogies and diagrams used in explaining concepts (Huddle *et al.,* 2000). It was specified that difficult concepts are not necessarily misconceptions but those concepts that are not easy to understand because they may contradict for

example, with what the learners have learned from other topics or disciplines. The sections highlighted below provide a detailed overview of how the discussion on the component ensued.

a) Identifying learner difficult concepts

A task for the tutorial discussion requested PPSTs to present different concepts identified as difficult for the learners to comprehend in chemical equilibrium and possible reasons contributing to the difficulties. Displayed below are some of the concepts identified as difficult in the tutorial.

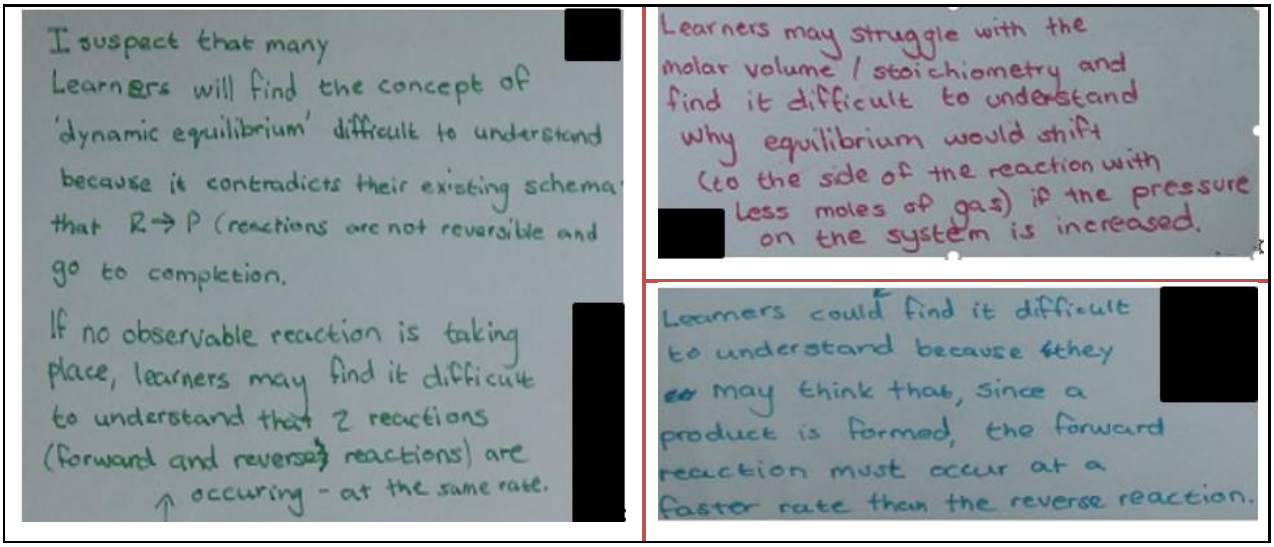


Figure 4. 4: A response on what is difficult for learners to understand

The following, amongst others, were presented as the concepts that are considered difficult to teach and to be understood by learners: (i) that reversibility within the reactions is a simultaneous process, for example; because there is no observable change taking place, learners might find it difficult to understand that both forward and reverse reactions are happening at the same time, (ii) the difference between equal rates and constant changes in individual reactant's concentration, (iii) the idea of conservation of mass law in a closed system, (iv) that solids and liquids do not affect chemical equilibrium, and (v) misapplication of the Le Châtelier's principle. The importance of always identifying the gate keeping concepts leading to the difficulty of subject matter was emphasised, so that they can be explicitly discussed in the classroom. This helps to clear up the confusion and challenges that some learners might have with conceptualisation of some aspects of the topic. Detailed discussions on two aspects of chemical equilibrium that contribute to the difficulty of the topic that were explicitly discussed are presented below. What prompted the direction of the discussion was the PPSTs inability to understand fully the causes of the difficulties

regarding these concepts, as well as how they can make these concepts easier for the learners to understand.

i) The dynamic nature of chemical equilibrium: At this stage, great emphasis was made on the importance of developing teaching strategies that enhance learner understanding of gate keeping concepts. An example of a concept of dynamic nature of chemical equilibrium was fully discussed. Discussions focused more on *what causes the difficulty* and *how this can be explained in a way that learners can efficiently comprehend*, using analogies and demonstrations that do not reinforce development of alternative conceptions. The difficulty around the dynamic nature of chemical equilibrium was linked to the simultaneous nature of the reaction which is not easy to observe at a macroscopic level. To explain this, there would be a need to enforce the concept of reversibility of reactions; that a forward reaction does not have to go to completion before a reverse begins and infuse within the explanation, the simultaneous nature of the reversibility of reactions at chemical equilibrium. Emphasis could then be made at this point about the equal rates of the forward and reverse reactions when the equilibrium state is achieved. A teacher would then need to use microscopic representations that can pictorially assist the learners to visualize such occurrences, complementary to how the reaction is represented symbolically and as seen at a macroscopic level.

ii) The difference between equal rates and constant changes in individual reagent's concentration: The difficult nature of this aspect was related to the fact that in the two graphs used (rate and concentration versus time graphs), one graph is the derivative of the other (see Figure 4.5 below). For example, a rate versus time graph is derived from the concentration versus time graph, where; $Rate = \frac{conc}{time}$. This then makes it difficult for the learners to understand what the two graphs entail.

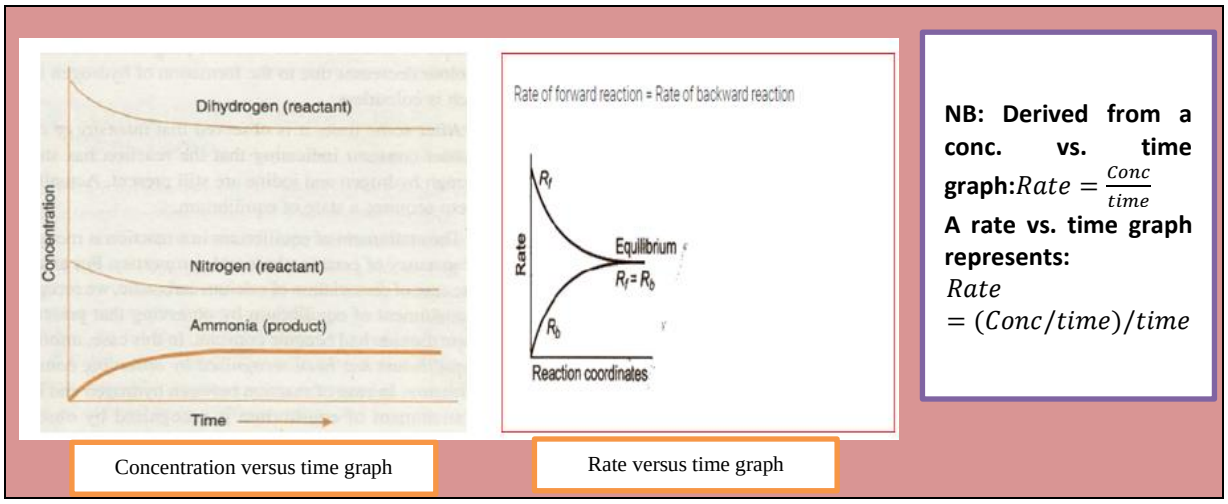


Figure 4. 5: Concentration and rate versus time graphs

What the concentration versus time graph shows is that when a reaction reaches a state of equilibrium, the concentrations of all reagents (products and reactants) do not change; they remain constant. Whilst the rate versus time graph shows that the rate at which the reactants form products is the same as the rate at which the products form reactants; thus, the rates are equal. This then implies that the ($Rate = \frac{Conc}{time}$) of a forward reaction at a specific time (a state of equilibrium) is equal to the ($Rate = \frac{Conc}{time}$) of a reverse reaction.

4.2.5. Sessions on use of representations

The aim of this discussion was for the pre-service teachers to develop the competency to use representations in a manner that brings understanding of difficult/abstract concepts. Representations are used as a way of helping to communicate the concepts to the learners, assisting to break the abstract nature of the concepts and creating a bridge to help the leaners to understand the concepts better. They facilitate learner conceptual understanding by helping the learners to make sense of the concepts under discussion (Mitchell, Charalambous and Hill, 2014). Nitz, Ainsworth, Nerdel and Prechtl (2013) refer to science as a multimodal subject which does not rely only on the use of verbal or written form of teaching strategies but require the use of a variety of representational graphs, diagrams, symbols and formulae amongst others. The three basic levels or kinds of representations: symbolic representations, macroscopic and sub-microscopic representations were discussed. The idea behind the use of all this is that chemistry is best understood when representations are used simultaneously across different levels. Representation at a symbolic level refers to the use of symbols and equations; macroscopic level refers to

"something that is large enough to be seen with the naked eye" (Bunce & Gabel, 2002; p. 914) whilst the sub-microscopic level talks to the models of matter; their natural arrangement and motion (Talanquer, 2011). The sub-microscopic representations are viewed as visualization tools for both the teaching and learning of abstract concepts as well as eliminating common learner misconception (Davidowitz, Chittleborough & Murray, 2010). Therefore, as emphasized in the session, the macroscopic level talks to the actual thing and what it looks like. The symbolic representations are the actual symbols, as used in chemical reactions while a sub-microscopic representation talks to how the molecules are naturally arranged. The great emphasis was on the choice of representations. It was explicitly emphasized that not every part of the representation explains what one wants to portray. Pin-pointing the exact part which talks to what one wants to convey within the representation is therefore especially important. Representations should help to develop learner cognitive understanding of the concepts being discussed and reinforce that which cannot be explained through the use of words alone. The PPSTs were made aware that they should always highlight and make explicit what they want the learners to understand from the presentations that they are using. A concentration versus time graph was given as an example that, not every part within the graph represents a Chemical Equilibrium; only a portion of it where concentrations are constant does (see Figure 4.5 and 4.6). This is why one would need to point out which part or feature within the representation portrays the message and aspect under discussion. As argued in Nitz et al. (2013), a skill in construction, interpretation, transformation and evaluation of representations in science is of great importance in helping to build a learner conceptual understanding. Examples of the use of multiple representations to demonstrate and explain specific concepts were presented as displayed in Figure 4.6 below.

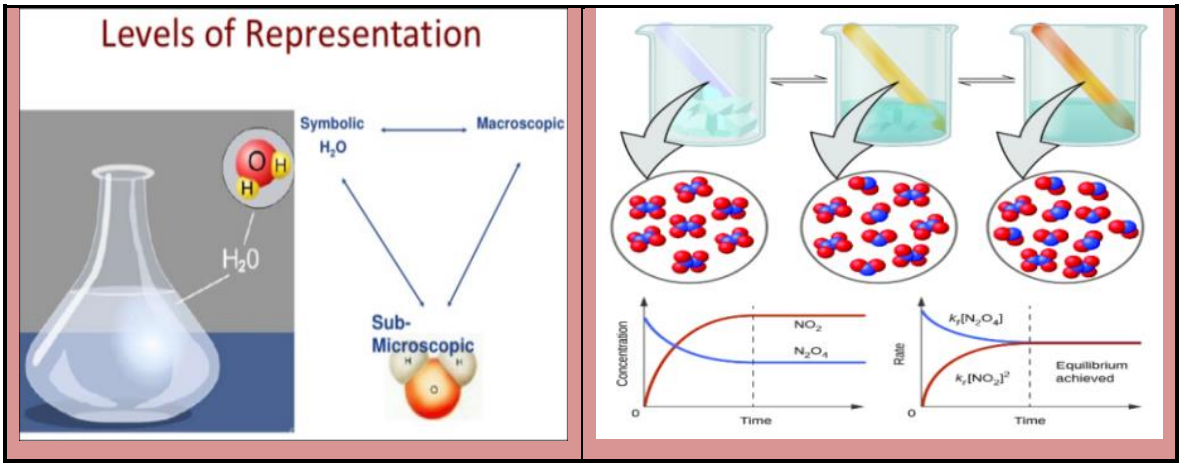


Figure 4. 6: Examples of multiple representation use to explain a concept

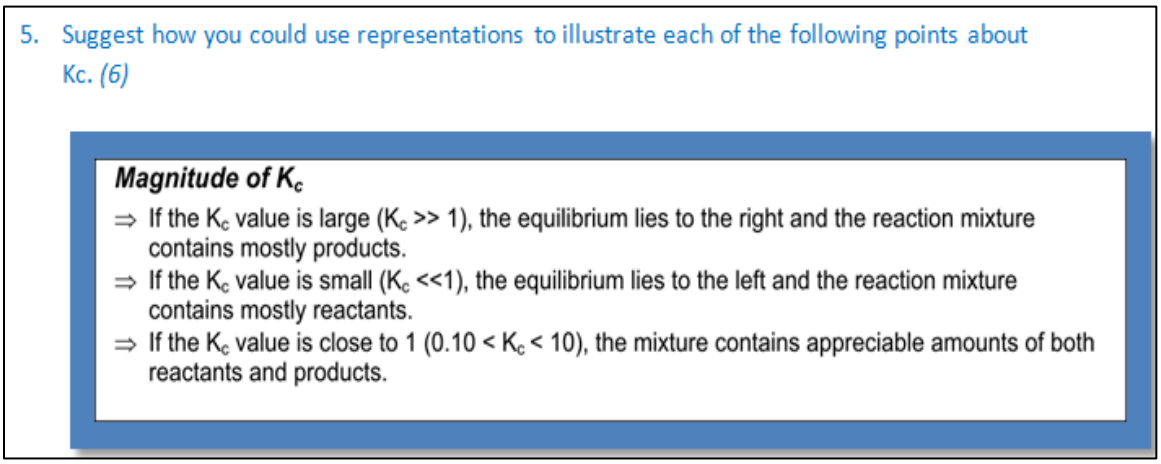
The first set of representations is a demonstration of water molecules presented using different levels of representations. Emphasis was made on the importance of using connecting words and explanations on the given representations to indicate what one is trying to put across. This was based on the given molecules of water which at symbolic and sub-microscopic level might induce an alternative conception that in a flask provided (where water is represented macroscopically), there is only one molecule of water.

The second demonstration is that showing decomposition of N_2O_4 into NO_2. Three levels of representations are used to show the arrangement of particles before the reaction occurs, until it reaches an equilibrium position. The first line of the representation shows the different colors portrayed by the system at different parts of the reaction; it is a signature of macroscopic representation. The second level portrays the arrangement of the particles of the reagents within the system; it signifies a microscopic representation. The last level represented by the two graphs shows the change in concentration and rates over time and the nature of both when the reaction has reached a state of equilibrium. The graphs also constitute the symbolic representations that provide the actual formulae of the reagents within the system.

It was further explained that using multiple representations helps the teachers to make explicit what they want the learners to understand where each level may bring about an aspect that may not be portrayed by another representation. Thus, these representations work together to help each other to explain a concept (making simple those concepts that are considered difficult and that also address and correct some of the misconceptions that learners might have regarding the topic). Wu et al. (2000) advocate that:

> "Being familiar with these representations and their usage in chemistry, therefore, is essential for the acquisition of expertise...The competence comprises a set of representational skills: the ability to see expressions with different surface features (e.g., changes in color) as representing the same principle, concept, or chemical situation, the ability to translate one representation of a chemical concept or situation into another one, and the ability to generate or select an appropriate representation to make an explanation, predictions, and justification. That is, representation competence includes the skills to use a range of chemical representations to do chemistry inquiry" (p. 122).

Task given to the PPSTs: The PPSTs were requested to discuss in their respective groups and suggest multiple representations that they would use in the teaching of the following concepts about the Chemical Equilibrium constant (Kc).


5. Suggest how you could use representations to illustrate each of the following points about Kc. *(6)*

Magnitude of K_c

⇒ If the K_c value is large ($K_c >> 1$), the equilibrium lies to the right and the reaction mixture contains mostly products.

⇒ If the K_c value is small ($K_c << 1$), the equilibrium lies to the left and the reaction mixture contains mostly reactants.

⇒ If the K_c value is close to 1 ($0.10 < K_c < 10$), the mixture contains appreciable amounts of both reactants and products.

4.2.6. Discussions on conceptual teaching strategies

Conceptual teaching strategies (CTSs) were referred to as teaching strategies employed to teach a particular concept, based on conceptual considerations. It is a teaching strategy that a teacher devises specifically for the concepts to be discussed and this cannot be adopted for teaching other concepts even within the same topic itself. For example, one can devise a strategy specific for teaching "the nature of chemical equilibrium" which will be different from a strategy for teaching "factors that affect chemical equilibrium". Evidence of multiple uses and an interaction between different components of TSPCK are the characteristic features of conceptual teaching strategies. Teachers should be seen to emphasize concepts, using specific representations and analogies and pointing out what they want the learners to understand. They should know when to use a particular representation and when to put emphasis as they explain (Harrison, & De Jong, 2005). As has been argued by Mitchell et al. (2014), representations can be used to help the learners to make some sense of and clarify concepts being discussed in the classroom, considering as they teach, the sequence in which to teach and emphasize concepts. CTSs were then referred to as strategies used to pull together all the considerations made from individual TSPCK components specific to a concept. Some of the strategies documented in the literature about how best to teach specific chemical equilibrium concepts were highlighted (Hanson, 2016; Ghirardi, Marchetti, Pettinari, Regis, & Roletto, 2015). An example of such strategies included an embedded conceptual teaching

strategy in the teaching of Le Chatelier's principle (Hanson, 2016). Discussed below are the examples of CTSs derived specifically for particular concepts.

i) A conceptual teaching strategy that aims to explain a concept: An example of a CTS was made of one explaining a state of chemical equilibrium. It was argued that a strategy could entail one indicating the steps that teachers would follow to teach this concept which includes using the graphs to explain that the rates are equal and the constant nature of concentrations at equilibrium, by pointing out explicitly what is equal and what is constant. Figure 4.7 provides a sample of the two graphs, highlighting areas within the graphs where equilibrium has been achieved.

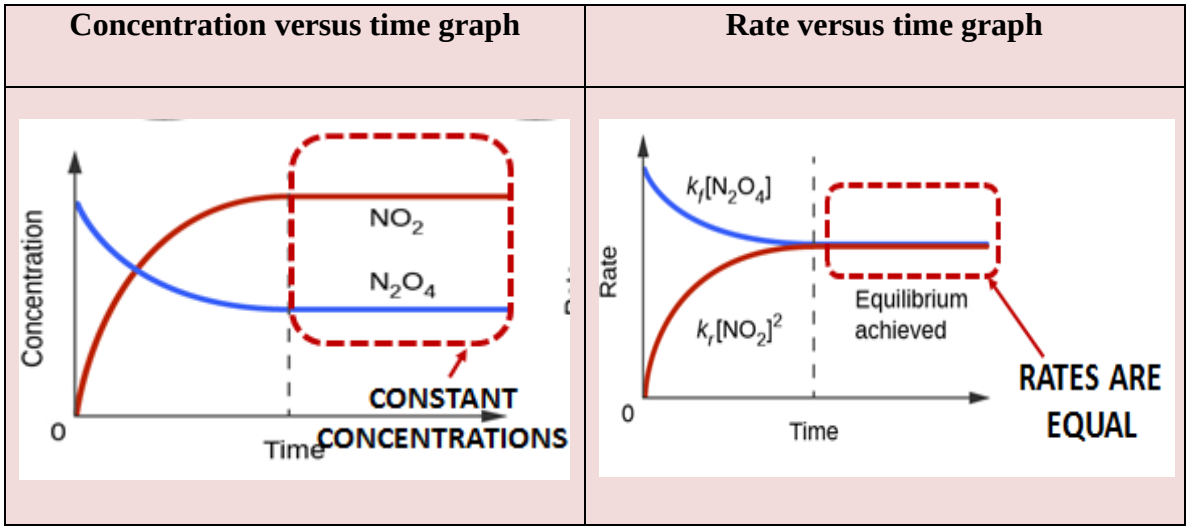


Figure 4. 7: A rate and concentration versus time graphs

ii) Conceptual teaching strategies that aim to address learner misconceptions: A CTS that addresses contradictory concepts within a topic can also be constructed. A teacher can demonstrate and use representations to explicitly explain such concepts. An example of the use of an application of the Le Châtelier's Principle was given. It was argued that the discussion of this can start with stating and explaining the factors that affect a state of Chemical Equilibrium. This would be followed by the discussion of the effect of each in order to bring forth the aspect of the Le Châtelier's principle. The principle refers to the change of an equilibrium state to counteract the effect of a disturbance. Accordingly, as the teachers explain this, they would need to make the learners aware that the rule does not suffice for all reactions, especially when a disturbance added is a liquid or a solid. It was indicated that a teacher could then have to use an equilibrium constant equation to explain the Le Châtelier's principle and why in does not otherwise suffice for other

equations. For example, the rule talks to the anomalies of liquids (such as water) and solids reagents which should not be added in the calculation of Kc, as represented in Figure 4.8. For a reaction, **2 $A_{(aq)}$ + $B_{(aq)}$ ↔3$C_{(aq)}$ + $D_{(s)}$,** Kc can be calculated, as shown in Figure 4.8.

$Kc = \frac{[Products]^x}{[Reactants]^y}$	$Kc = \frac{[C]^3}{[A]^2[B]}$

Figure 4. 8: Equations on the calculation of equilibrium constant (Kc)

The first equation shows a general equation for the calculation of Kc, which is through dividing the concentration of products by the concentration of the reactants, where the superscripts represent the number of moles of each reagent in a balanced chemical equation. The second equation is used for the calculation of Kc for the given equation. In this equation, the concentration of D is excluded from the calculation of Kc because, as it was mentioned above, solids and liquids are not included in the calculation of Kc. The reason for their exclusion is that their concentration is equal to 1; hence their inclusion in the equation is not necessary. Using this in collaboration with the Le Châtelier's principle when explaining the impact of a disturbance at an equilibrium state, can help the learners to make a good judgment in terms of how the equilibrium position will shift when the concentration of a reagent is manipulated within the system.

4.2.7. Pulling components together

Emphasis was made on the importance of the TSPCK construct used to reason through and transform content into a teachable form. The following were listed as the characteristics of the framework of content knowledge transformation: *(i) helps the teacher to structure and understand the scope of how much to teach within the topic, (ii) gives one a clear picture of what to put in place before a topic is discussed, (iii) helps a teacher to look at the topic in totality, brings in the sequence through which to structure the topic, (iv) informs the conceptual strategy to use in class, what to say and when to say it, how and why to emphasize concepts.* For example, it provides an essence of what to do when concepts are difficult, how to teach them and what needs to be emphasized, when and how. The discussion made explicit links between the components of content

knowledge transformation, using Chemical Equilibrium concepts to highlight how different concepts can be explained and made more accessible to the learners.

4.2.8. An introduction of a CoRe

A content representation (CoRe) instrument originally developed by Loughran et al. (2004) has been used for purposes of capturing and portraying the teachers' pedagogical content knowledge (PCK). It assists teachers to think about and convey their understanding of the topic content (Alonzo *et al.,* 2019). At the end of the intervention, it was important to help the PPSTs to collate the thoughts that they have done in thinking through the topic, one component at a time. They were then introduced to an instrument that helped them to organize their thoughts into a systematic way where they could go back to their thoughts and think about them in conceptualizing their teaching strategies (a CoRe). For this particular case, the CoRe was used with a slight emphasis, as an instrument to capture PPSTs' own thinking and collating the thoughts that had been generated from the discussions and reasoning through the topic, using individual components. It consists of questions that seek to prompt thinking into the individual components of the TSPCK and it allows room for them to think through and pull things together into a functional teaching strategy in consideration of individual concepts of the topic.

The pulling of these thoughts together affects the transformation of content knowledge because all these components work together. It is when they are thinking through all these issues (as prompted by the CoRe questions) and drawing from what they learned from each component that they are then enabled and have a better chance to transform their content. It is the interaction that enables one to draw from different components that determine the quality of planning and the teaching observed on the teacher's reasoning and explanations of concepts.

4.2.9. Evaluation of the construct

At the end of the intervention, the PPSTs were given a chance to explain their sense of value of having been exposed to this TSPCK framework. This evaluation gave them a chance to evaluate the usefulness of this framework and its ability to enable them to think through their plan for teaching. On their evaluations, the PPSTs showed that they benefitted greatly from the discussions, as seen from the extracts below.

Furthermore, throughout this course I have learned the value of being in a community of practice. This comes from realizing that only through collaboration with colleagues, rigorous and robust debates on key ideas within the 5 aspects of TSPCK (i.e. Curricular Saliency, Misconceptions, What is difficult to teach, Representations and Conceptual Teaching Strategies) and lastly access to research conducted on all these aspects by educational professionals, that planning towards effective teaching can take place. In addition deep understanding of topics can take place further enabling teachers to be effective in their practice if the above practices are adhered to.

I believe and think that I have learnt a lot throughout the sessions that enabled me to develop a CoRes. In overall, I have learnt how to develop conceptual teaching strategies through effective and thorough considerations into curricular saliency, learner prior knowledge and use of relevant and effective representations. I therefore have reason to believe I have learnt and I can put it into practice. The success of my learning and teaching improvement would be determined by the extent to which I apply what I have learnt.

Figure 4. 9: PPSTs' responses on their overall views about the intervention

Their anonymous comments on the evaluation of the intervention also provided a positive feedback, which indicated that they benefited from the intervention (see Figure 4.10 below).

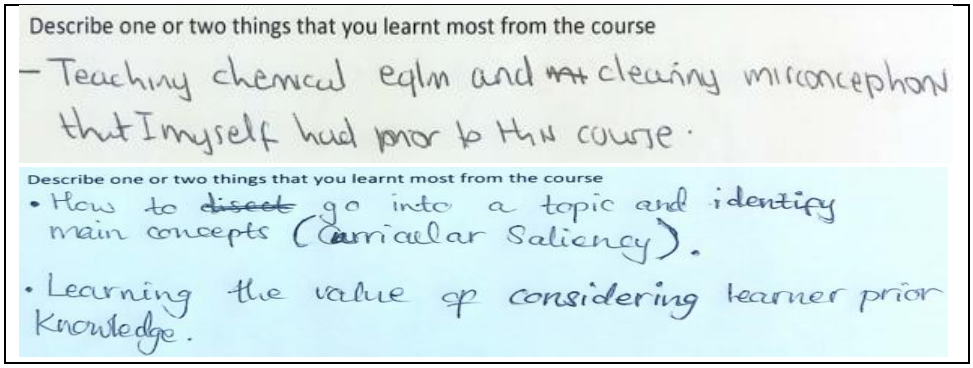


Figure 4. 10: Pre-service teachers' anonymous comments on their gains on the course

From their open written reviews, as presented in the examples above, the evaluations were largely positive, and this seems like the recognition of the framework as an enabler and tool in helping how to think about the topic content when planning to teach.

4.3. Conclusion

The discussions made in this chapter were intended to explicitly explain how the intervention on content knowledge transformation through the use of the five components of topic specific PCK transpired with a cohort of PGCE physical science pre-service teachers. The descriptions were made in order to explain the pre-service teachers' pedagogical reasoning and content knowledge transformation development throughout the intervention process. The examples given from the

tutorial presentations, TSPCK test-tools and assignment responses provide a sense of how their thinking processes and content knowledge transformation ability ensued across the intervention.

As it was indicated earlier, the intervention occurred within a continuous dedicated time of 6 weeks within their one-year physical science PGCE fulltime programme. The intervention was characterized by a lot of interactions and discussions. The environment was adequately open to allow the PPSTs to make and correct their own mistakes. They also developed confidence in making mistakes in front of each other and talking about their own weaknesses about the intervention topic. For example, during the discussions, they identified their own misconceptions and realized that other PPSTs also had them. These helped them to engage fully in discussions and really have the desire to work things out when they noticed that the discussions were actually unpacking and providing them with a platform to grow. An example of a misconception that the teachers shared and was corrected in the discussions has been discussed in section 4.3.2.

In the end, it was important for the PPSTs to evaluate the impact of this intervention. Although it was a continuous process, this was the first time that the PPSTs were exposed to it. It was a vehicle that introduced them to pedagogy and an entrance to the content knowledge because of the content specific nature of the construct. Through use of the evaluation responses presented above, an evidence of growth was displayed. This framework of content knowledge transformation through the use of the five components of TSPCK influenced the teachers' thought processes and how best to organize their content when planning to teach, as demonstrated in Figure 4.9 and 4.10. The evidence of the impact of the intervention, however, is discussed in more detail from chapters 5 to 7.

The next chapter discusses the impact of the intervention on the PPSTs' reasoning, as displayed at a planned level**.** The analysis is focused on data collected from the two pencil and paper TSPCK tools (TSPCK-tests and CoRes), and the tutorial presentations.

CHAPTER 5

THE DEVELOPMENT OF PLANNED TSPCK FOR PGCE PRE-SERVICE TEACHERS

The previous chapter provided a detailed description of the intervention geared to improve the quality of TSPCK in Chemical Equilibrium. In this chapter, I determine the impact of the explicit intervention on the quality of PPSTs planned TSPCK in chemical equilibrium. I start by providing a summarized procedure of the analysis followed and then present the overall patterns of the results, reflecting on the impact per person and per TSPCK components. I follow this analysis with cross collaboration of the extracts from different sources to illustrate the observed shifts. I close the chapter with a summary of the core findings.

5.0. Introduction

The key focus of this study was to track how the PPSTs translate their personal TSPCK (plTSPCK), developed in the context of planning to teach, into the actual classroom context (eTSPCK) and its ultimate impact on learner achievement. This chapter presents the first result on the impact of the intervention on the quality of the PPSTs planned TSPCK. It is considered planned because it is TSPCK evident in the kinds of teacher tasks related to teaching a topic (Mavhunga, 2016). It is important to state explicitly that the improvement in the quality of TSPCK by the PSTs as a result of an explicit intervention (Mavhunga & Rollnick, 2017) would not be a new knowledge finding but an important baseline from which the translation of acquired TSPCK into a classroom teaching and the subsequent impact on learner performance could be determined with credibility. Several studies that employed the same intervention reported positive findings with respect to the improvement of the quality of TSPCK in the topic of the intervention. Examples include (Rollnick & Mavhunga, 2014) for the topic 'electrochemistry' and (Pitjeng, 2015) in the particulate nature of matter (Mavhunga *et al.*, 2016) in electrical circuits, including a study on chemical equilibrium (Mavhunga & Rollnick, 2013). However, these studies were conducted with traditional PSTs who were registered in a teacher qualification degree, the B. Ed. degree, thus had had four years of development in other pedagogies. As alluded to before, this study is with PPSTs who had a limited exposure to the methodology studies.

In order to determine the improvement in the quality of the PPSTs' planned TSPCK in the topic of intervention, multiple data sources were used to establish (i) shifts and also (ii) to capture

evidence of TSPCK as it was developing during the intervention. As explained in Chapter 3, in order to establish the shifts, the PPSTs completed a set of TSPCK tests on Chemical Equilibrium used as sets of pre, post-tests and a CoRe which was administered after the intervention, at about the same time as the post-TSPCK test. Accordingly, tutorial sessions constituting group presentations and discussions were used to capture their TSPCK as it was developing during the intervention.

This chapter begins by presenting the findings of the study on the overall patterns of shifts in the quality of TSPCK which are regarded as planned TSPCK. These shifts are derived from scoring the written responses from the TSPCK tool described in chapter 3. A TSPCK test tool, which is designed specifically for testing the teachers' pedagogical reasoning and knowledge of the topic of Chemical Equilibrium (Mavhunga, 2014) is organized according to the TSPCK components aimed at analyzing the responses to a particular component (Mavhunga, 2014). The analysis of this TSPCK tool was done through the use of a four-criterion based planned TSPCK rubric by Mavhunga (2012), scoring from 1 to 4 as alluded to in Chapter 3. This analysis illuminated the shifts in the quality of TSPCK of the PPSTs across the intervention. Following this is an in-depth analysis of those patterns which pulls qualitative extracts from different sources of data collected in the tool itself during the intervention in order to reflect the nature of the shifts that are presented in the overall patterns. Data used to corroborate the analysis of the TSPCK tool comes from either a tutorial and or, a CoRe which was done towards the end of the intervention.

An individual PPST's response is also compared to a similar response from the CoRe (Loughran *et al.,* 2004). The use of CoRe allows one's response to be more elaborate and can provide a detailed overview of the PPSTs' knowledge for teaching a topic. Different from the CoRe which requires PPSTs to generate their own responses on the prompts, the TSPCK test tool has a list of responses to choose from and expand on. The PPSTs' responses and explanations of the questions on this tool enabled the study to explain their planned TSPCK and reasoning about the topic of intervention. This also enabled the establishment of the PPSTs' understanding of individual components of TSPCK with respect to the chemical equilibrium topic concepts.

All the tutorial presentations and discussions were also on the components of TSPCK. These discussions were designed to capture the PPSTs' thought processes spot on, as they are learning

to reason about all the components of the TSPCK construct. This permitted the study to capture their TSPCK as it was developing. Each tutorial session involved group presentations and explicit classroom discussions of the concepts related to individual TSPCK components. The PPSTs were assigned to work in permanent pairs for the duration of the intervention.

5.1. Shifts in the quality of PPSTs' planned TSPCK

Table 5.1 presents raw TSPCK scores obtained from a PGCE class of 2018 consisting of a total of eight PPSTs. The scores demonstrate the PPSTs' quality of TSPCK obtained from their pre- and post-intervention TSPCK test-tools. The first column on the table presents the pseudonyms used in this study to refer to the eight PPST participants. Columns two to six display the raw TSPCK scores obtained by individual PPSTs on the pre- and post-intervention TSPCK tests with respect to all five components of content knowledge transformation abbreviated **LPK**, for learner prior knowledge and misconceptions, **CS** for curricular salience, **R** for representations, **WD** for what is difficult to teach and understand, and finally **CTS** for conceptual teaching strategies. The pre-intervention scores are outside the brackets within each of the five columns whilst the post-intervention scores are enclosed within the brackets. The seventh column displays each PPST's average TSPCK score. The last column presents the individual PPST's proxy score. The last two rows display the group average and proxy average scores, respectively. The average scores which are in fraction form were rounded up or down and the rounded scores presented as proxy scores as displayed on Table 5.1. The *group average TSPCK scores* for pre and post-test were calculated using the individual PPST's score for each knowledge component, whilst the *individual PPST's average score* is the person average score for all components combined, followed by the corresponding proxy for each. A proxy average calculation was done so that those scores could easily be matched to the rubric since the rubric scale is presented in whole numbers and not fractions (see Table 5.1).

The TSPCK rubric used in this study to capture the PPSTs' planned TSPCK calls for the interaction of the components with others. Each category of the rubric reflects the extent to which the response displays not only the understanding of a component but also the ability to interactively use two or more different components in an explanation (Mavhunga, 2014). Even though each component appears to be scored individually, the score is given based on the ability of the PPST to pull together two or more components of TSPCK in their reasoning. It is in line with Park and Chen

(2012) that PCK is defined not on the basis of individual components but also on the interaction and interplay of the components that make it up. Adding the scores of these components gives us an overview of many interactions observed in the PPSTs' responses. This implies that the proxy averages indicate the overall interactive use of TSPCK components demonstrated in the responses and explanations that are given by the PPSTs and also reveal the PPSTs' TSPCK proficiency at a planned level. The PPSTs' quality TSPCK in this study, therefore, is defined in terms of their understanding of individual TSPCK components as well as their interaction with each other. In this study, I consider scores categorized at limited and basic levels as low. They display the low quality of TSPCK for the PPSTs. On the other hand, the scores categorized as developing are considered in this study as high, and therefore reflect a high quality of TSPCK whilst categorizing a score as exemplary places one at a sophisticated level of TSPCK quality.

Table 5. 1: Raw pre- and post-intervention TSPCK-test scores (N=8)

Pre-service teacher	**LPK**		**CS**		**R**		**WD**		**CTS**		**Individual Average**		**Individual Proxy**	
	Pre	Post	Pre	Post	Pre	post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Mandla	2	3	1	2	1	2	2	3	1	3	1.4	2.6	1	3
Jane	1	3	1	3	1	2	2	3	1	3	1.2	2.8	1	3
Lerato	2	3	1	3	1	3	2	3	2	3	1.6	3.0	2	3
Daniel	1	3	2	3	2	3	2	4	1	3	1.6	3.2	2	3
Sara	1	3	1	3	1	3	2	3	3	3	1.8	3.0	2	3
Katleho	1	3	1	2	2	3	2	3	2	3	1.6	2.8	2	3
Brown	1	2	1	3	1	2	2	3	1	2	1.2	2.2	1	2
Noma	1	3	1	3	1	2	1	1	3	2	1.4	2.2	1	2
Average	1.37	2.88	1.13	2.75	1.25	2.50	1.88	2.88	1.75	2.75	1.48	2.75	1.50	2.75
Proxy	1	3	1	3	1	3	2	3	2	3	2	3	2	3

The scores in **Table 5.1** demonstrate an improvement on the overall TSPCK quality for all the PPST participants across the different components of content knowledge transformation. Two patterns based on the proxy averages are displayed on the table. The first pattern is focused on *the individual PPST's average/proxy scores* (the 7th and 8th columns of Table 5.1). The second pattern is derived from *individual component scores which translated into the overall group average/proxy scores* highlighted by the last two rows (11 and 12) on the table.

5.1.1. Individual PPST's average/proxy TSPCK development

This section presents the person average TSPCK score development from the pre- and post-intervention TSPCK test tools. The graph in Figure 5.1 displays the shifts in TSPCK quality for these two tests.

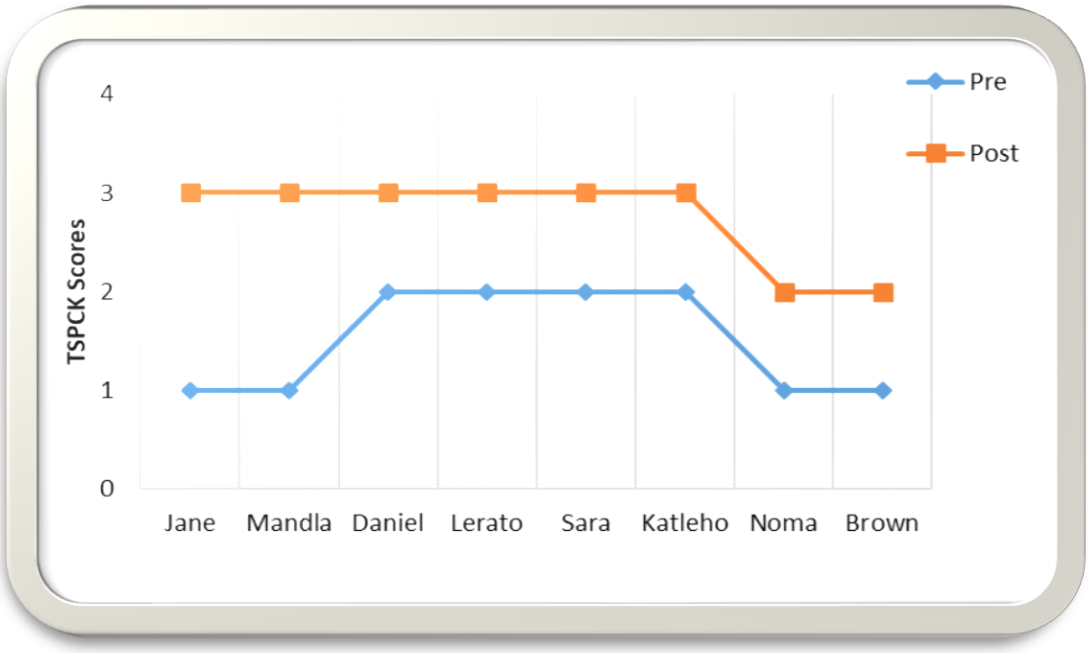


Figure 5. 1: Average shifts in pre- and post-individual scores

Two distinct trends are observed in Figure 5.1. These are: (i) a 2-category jump increase and (ii) a 1 category jump. Two PPSTs **(Jane and Mandla)** experienced a 2-category jump from 1 to a maximum score of 3 after the intervention; this is a high-quality jump. The second trend is that of teachers who experienced a 1 category jump, yet they landed at different levels of development after the intervention. In this trend there is a group of four PPSTs **(Daniel, Lerato Sara and Katleho)** who experienced a 1 category jump from a score of 2, to 3. There is also a high-quality jump because of a higher score obtained after the intervention. A second group (in the second trend) is of two PPSTs **(Noma and Brown)** who also experienced a 1 category jump from a much lower level 1 to level 2. In this second category, the pair's TSPCK quality is still quite low after the intervention, though there is an improvement that can be accounted for and attested to as effected by the intervention. Overall, six out of a total class of eight PPSTs experienced a high-quality shift (scoring at a developing proficiency level), whilst two experienced a low-quality shift

with their scores averaging to a basic level proficiency of TSPCK after the intervention. The two PPSTs' TSPCK quality still needs more development into a level of high quality so that their planning and teaching may improve learner accessibility and understanding.

For a closer look and insight into the average scores presented in **Figure 5.1**, the summary of all the eight PPSTs' TSPCK across all components is graphically presented in **Figure5.2.** This situation provides a broader visual perspective of the shifts in quality development of the individual PPST's TSPCK proficiency level across all components.

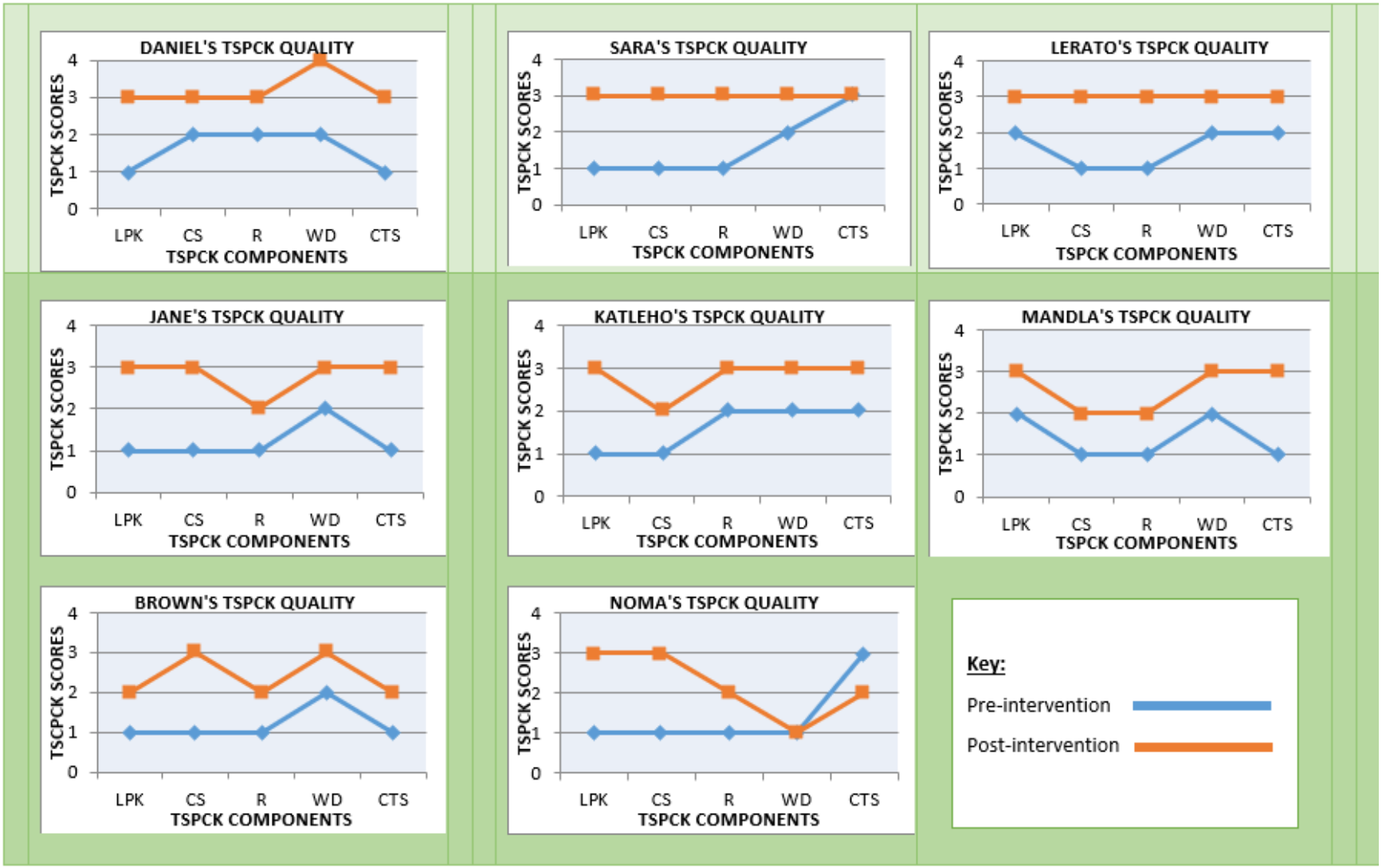


Figure 5. 2: Graphical representations of individual PPSTs' pre- and post-TSPCK scores

Overall, the graphs in **Figure 5.2** indicate that the person average TSPCK quality for all PPSTs significantly improved after an exposure to the intervention. Each person experienced major shifts in scores across all components. There are three categories displayed in Figure 5.2. These are: (i) those who experienced extremely high improvement-a 2 category jump, mostly from 1 to 3; (ii) those who experienced an improvement the same as the others, but their scores are higher-a 1 category jump from 2 to 3; and (iii) those who performed lower than the majority- a 1 category jump from 1 to 2. The TSPCK displayed by such PPSTs (those that scored a maximum 2 after the intervention) is of low quality which could affect their ability to transform their content knowledge for learners' efficient accessibility and comprehension negatively.

For example, four of the eight PPSTs (Daniel, Sara, Lerato and Jane) experienced the greatest shifts across all components. Two of them (Sara and Lerato) scored at a developing level on all the five components of TSPCK. Daniel scored a 3 on four TSPCK components and a 4 on a component concerning what is difficult to understand which is remarkable. Furthermore, Daniel, Sara and Jane's TSPCK improved with two levels for three components. As it is reflected by their TSPCK score increase, this implies that overall, the four PPSTs' reasoning and thinking about their teaching of the topic of chemical equilibrium has significantly improved. Two of them (Jane and Katleho) scored at a developing level in four components; their TSPCK quality was classified at a basic category in one component. Mandla's TSPCK scores were classified at a developing level in three categories and at a basic level in two other TSPCK components. Brown scored 3 in two TSPCK components and 2 in the remaining three components. The eighth PPST, Noma, experienced the least improvements in her TSPCK quality. She scored 3 in two TSPCK components, scored 2 in one, had a decrease in score in one and experienced no increase in another.

Section 5.2.2 provides a detailed overview of how the PPSTs performed in each component as a group. The section explains the average group performance per TSPCK component. Figure 5.3 displays the group averages obtained from the individual PPST's performances shown in Figure 5.2.

5.1.2. The group average/proxy TSPCK development per component

As presented earlier in this chapter, two major patterns were observed and displayed on Table5.2. Firstly, the scores were presented as average individual scores where an average and a proxy for each PPST participant were calculated. This situation was then discussed in detail in **section 5.1.1.** The second most important identified pattern is of the group average TSPCK score per components. It indicates how the participants performed in each component as a group. It also provides us with a clear picture of how the group's TSPCK quality shifted per component. For this part and for every component of TSPCK, the individual PPSTs' TSPCK scores were added together and their average as a group obtained.

Taking a closer look into this second pattern; it is observed that there is an overall increase in the group average/proxy TSPCK quality across all the components. **Figure 5.3** graphically displays the group proxy scores per component demonstrated by the last row on **Table 5.1.**

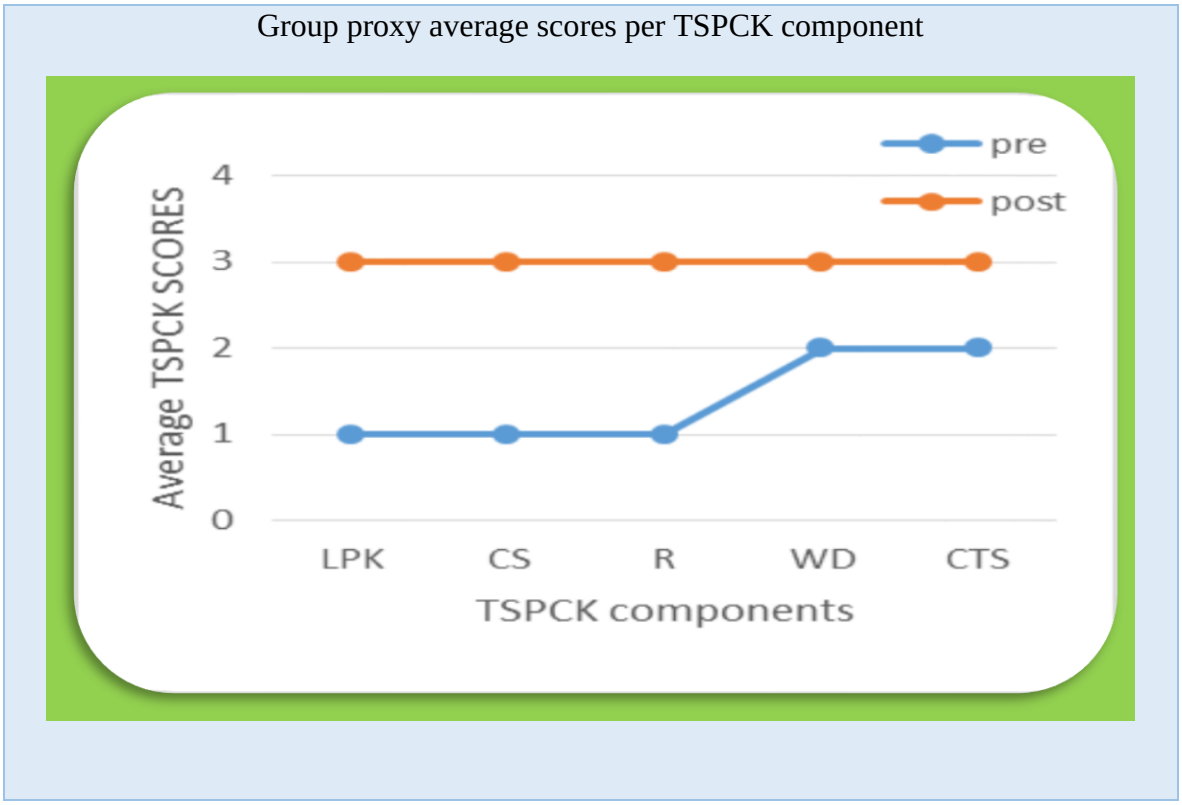


Figure 5. 3: The shift in quality across all TSPCK components

Looking closely at **Figure 5.3**, it is noted that the group experienced a shift in TSPCK quality across all the components. The group average scores improved from lower scores on pre-tests to

higher scores in the post-tests. This means that on average, the PPSTs' TSPCK proficiency and quality had improved after the intervention. For example: (i) the group experienced an average jump of 2 quality TSPCK categories in the first three TSPCK components, learner prior knowledge including misconceptions (LPK), curricular saliency (CS) and the ability to use representations (R) from 1 to 3. (ii) On the last two components (WD and CTS), the group experienced a 1 category jump, from 2 (basic reasoning) to 3 the developing TSPCK proficiency level. On average, the group experienced a high-quality jump in all the categories with an average of 3 across all the five TSPCK components. Thus, on average, the TSPCK quality across all components was categorized at a developing level of proficiency after the intervention.

To analyze these shifts more closely, the group proxy scores were presented graphically across all the components of TSPCK in Figure 5.4. This situation provides a summary of the individual PPST's performance within each component. This enables one to look more closely into how each participant's score compares with those of the other group members within the same component of TSPCK.



Figure 5. 4: The group average TSPCK scores across all components

The graphs in **Figure 5.4** show the greatest development and shifts in the PPSTs' scores in two TSPCK components of CS and LPK. At least five out of a total of eight PPSTs experienced a 2-category jump from a limited to a developing proficiency after the intervention in both components. *The number of PPSTs experiencing this high-performance jump decreased to three, two and one PPSTs in the components of* ***CTS, R*** *and* ***WD,*** *respectively*. The two components of curricular saliency and learner prior knowledge saw the greatest shifts in terms of quality jumps with more PPSTs experiencing a 2-category shift from 1 (limited TSPCK quality) to 3, a

developing quality post the intervention. This shows a remarkable development by the PPSTs which is very important. The aspect of CS which links more directly to content knowledge is one important in TSPCK development. Absence of or limited content knowledge can hardly make it possible for one to know what is important within a topic that needs extra emphasis (aspects of curriculum saliency). Two PPSTs' TSPCK quality of this component was not appealing even after the intervention. The two participants (Mandla and Katleho) scored at a basic level after the intervention, demonstrating a low level of TSPCK development, possibly because their content knowledge is low.

In general, however, at least more than half of the PPSTs scored at a developing level across all the components of TSPCK; *seven out of eight for an **LPK** component, six for **CS, WD** and **CTS** and, lastly, four in a component involving the use of **R***. On a component of ***WD**, one of the PPSTs scored at an exemplary 4, after the intervention.* This was the highest level of proficiency displayed by the rubric.

From Figure 5.4 it is observed that there are four PPSTs (Daniel, Sara, Lerato and Jane) whose TSPCK quality grew remarkably. Three of the four participants (Daniel, Sara and Lerato) demonstrated a high TSPCK quality shift and development across all the components scoring at a developing proficiency in all the five components after the intervention, with Daniel scoring at an even higher exemplary level 4 in one component. Furthermore, Daniel, Sara and Jane exhibited an astonishing two-category increase in three TSPCK components. Jane and Katleho, scored at a developing category in four TSPCK components and at a basic level in the last component. Three other participants experienced the least improvement within the group, with Noma experiencing the lowest in the whole group.

The overall quality of TSPCK for the group on the pre- and post-intervention TSPCK tests were from the basic to the developing proficiency, respectively. The group average TSPCK score was obtained by combining all the group component averages, averaged to their number for both the pre and post-test scores which are 1.5 and 2.75, respectively. The two were then rounded up to 2 (a basic category for the pre-test) and 3, (a developing category for the post intervention test). These scores indicate how on average, all PPSTs' combined performed before and after the intervention across all the components.

The PPSTs' responses to the TSPCK tests (**sections 5.1.2a and 5.1.2b**) are used to provide closure into how the scores were assigned. These are presented in the form of pre- and post-intervention extracts per TSPCK component. Extracts from various PPSTs have been used in order to give an overview of how the intervention affected the group's reasoning and thinking about their teaching of chemical equilibrium in **section 5.1.2a**. **Section 5.1.2b,** on the other hand presents extracts by one PPST across the five TSPCK components. This also helps us to explain the learning progression and development across all the components, by an individual PPST across the intervention. It provides an insight into how the individual PPSTs' reasoning and thinking about teaching this topic were affected by the intervention.

The analysis of the overall patterns above showed that both patterns on overall components and persons reflect collaboratively visibly noticeable shifts in the quality of PPSTs' TSPCK. While the outcomes in the improvement of the quality of PPSTs' TSPCK was expected on the basis of the previous studies, it was however, especially important to analyze the data collected for this study for improvement in the quality of TSPCK in the topic of intervention in order to establish a credible baseline from which the train of development of teacher knowledge into learner performance could be based. The section that follows presents an in-depth analysis on the TSPCK quality shifts presented above. A closer look at the patterns occurs, using data from the TSPCK tools and other sources of data with the purpose of corroborating the findings. The data used to corroborate the findings from the TSPCK tests include tutorial session presentations and a post-intervention CoRe that the PPSTs wrote right after the intervention.

5.1.2a. A closer look into individual components; the meaning behind the scores

Development in Learner prior knowledge-(LPK); *a high-level jump*

Under this component of LPK, the PPSTs were asked to choose out of four responses given, the best one that they would give to a learner who had a doubt and asked the following question: *"Do both forward and backward reactions actually take place if a closed system is at equilibrium?"* The PPSTs were then requested to expand on their choice of response. Displayed in **Figure 5.5** is an extract from the TSPCK test that the PPSTs responded to. It highlights the learner's doubt on a concept regarding reactions that are at a state of equilibrium.

CATEGORY A:

1. In a classroom setting, which of the following responses will you choose to answer a learner who seems to be in doubt and asks you:

"Do both the forward and the backward reaction actually take place if a closed system is at equilibrium?"

Response A: Yes; the rate at which the forward reaction occurs is the same as the rate at which the backward reaction occurs. We do not see them because both reactions happen under a microscopic eye.

Response B: Yes; for a reaction to be considered as at equilibrium, the rate of the forward reaction is the same as the rate of the reverse reaction. As products are formed, they decompose or react with each other and form reactants. In this way the reaction is kept at equilibrium.

Response C: Yes; a reaction that is at equilibrium has a forward and a reverse reaction. The forward reaction produces products, and the backward reaction produces reactants. Sometimes the concentration of products is higher than reactants, sometimes vice versa.

Response D: None of the above.

Choose your response and use the space below to expand on your choice.

Figure 5. 5: A TSPCK tool extract on chemical equilibrium

The extracts presented in **Figure 5.6** demonstrate the reasoning given by one of the PPSTs, "Jane" in response to the learner doubt. Related responses and reasoning with regard to learner misconceptions extracted from tutorial sessions and or CoRes are used as supplementary data to explain Jane's development across the intervention.

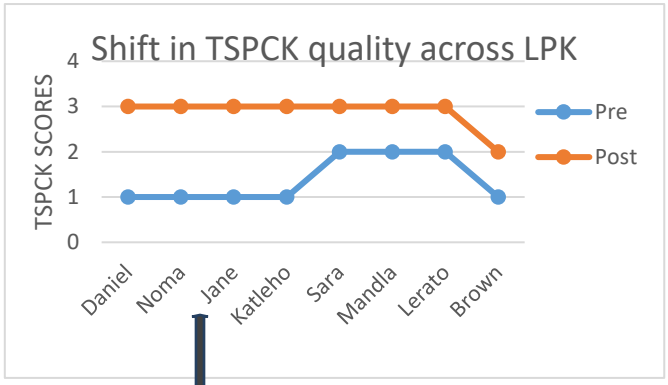
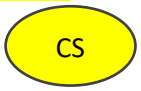
TSPCK scores	Pre-test response	Post-test response
 Jane scored 1 and 3 in the pre/post TSPCK tests	At equilibrium, both reactions are occurring simultaneously-the forward and reverse reactions. As they are both occurring at the same rate  A one component TSPCK Map	Once equilibrium has been attained, the net change in concentration of the reactants and products will remain constant until the equilibrium is disturbed (CS and LPK). In a closed system, it may appear if no change is taking place as the concentrations of all participating substances remains constant, but there is a continuous simultaneous forward and reverse reaction occurring (WD). The relationship of the concentrations of reactants and products to one another is reflected in the equilibrium constant.  A three component TSPCK Map

Figure 5. 6: Jane's qualitative data responses in the component of learner prior knowledge

For the first attempt of response to this question, Jane scored 1, the first category on the TSPCK rubric. This meant that her reasoning ability was considered limited. The response provided by Jane in Figure 5.6 does not indicate her recognition of the learner doubt and hence no attempt within the response and reasoning provided to address the learner doubt. In her response, Jane does not explain (to the learner) why there is both a forward and reverse reaction taking place at equilibrium. Her explanation was that; *"At equilibrium, both reactions are occurring simultaneously-the forward and reverse reactions. As they are both occurring at the same rate in a closed system".* This explanation, however, does not help the learner to understand and remove the doubt that he/she had about the reactions at equilibrium. Jane's repeat of the standard definition with no attempt to explain to the learner why the two reactions are still happening, does not help to remove the doubt that the learner has, hence her reasoning was categorized at a limited TSPCK proficiency level 1.

After the intervention, Jane's score had increased to 3, a developing category. This indicates a 2-category quality TSPCK jump. An improvement in Jane's score in the TSPCK post-test could be attributed to the intervention as reflected in her improved reasoning. The instances that revealed Jane's use of two or more TSPCK components interactively to describe a concept were considered as an episode of interest. To describe such interactions and the interplay of TSPCK components, a TSPCK Map was provided (as in Park & Chen, 2012). This is based on the existing literature which argues about PCK as not the sum of individual components but their interactions (Abell, 2008). In this study, TSPCK is also considered as reflected by interactions of the five TSPCK components, as alluded to in Aydin et al. (2015). The TSPCK Maps serve to describe the interactions that are seen in PPSTs' reasoning of individual TSPCK components, as they draw on others when explaining concepts.

An examination of Jane's post-intervention test of the same item demonstrated a different result and depth in the given response. She demonstrated a precise understanding of what happens at equilibrium. She first begins by emphasizing what happens at equilibrium and this is followed by her addressing the learner's doubt as she explains one aspect of Chemical Equilibrium that might have resulted in the confusion. The first statement that Jane gives in the response to the question is "*Once equilibrium has been attained, the concentration of the reactants and products remains constant until the equilibrium is disturbed".* Beginning the response to the learner's doubt with an

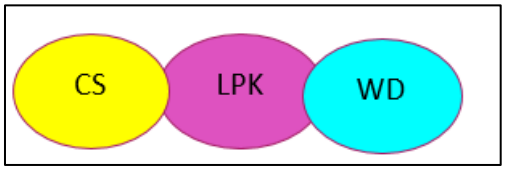
explanation of what happens at equilibrium gives the learner the basis of all reactions at equilibrium. It creates a foundation for the learner's understanding of the process. This brings forward the aspect of **curricular saliency-CS** in her emphasis of what is important. This explanation also shows that the PPST is aware of learner misconceptions with regard to the concentrations of reactants and products at equilibrium. For example, when asked to identify learner misconceptions on Chemical Equilibrium in a CoRe, Jane stated that the learners believe that "*at equilibrium the concentrations of the products are equal to the concentrations of the reactants".* This implies that Jane considered important, the component of **LPK** in her response. This explanation helps the learners to understand that concentrations are constant and not necessarily equal.

To explain this further, Jane identifies the gate keeping concepts that might have contributed to the learner doubt. She adds *"In a closed system, it may appear as if no change is taking place as the concentrations of all the participating substances remains constant but there is a continuous simultaneous forward and reverse reaction occurring".* The concept of reversibility of reactions happening at the same time and rate at equilibrium has been identified by research as **difficult to understand-WD** because at a macroscopic level, there is no observable change. This confuses the learners because it makes them to think that the reaction has stopped. The explanation that is given by Jane removes that doubt by clarifying why the two reactions still happen even though it appears as if there is no reaction at all.

Jane further reports in the CoRe that the concept of reversibility is a source of learner misconceptions, where the learners think that *"the reverse reaction only proceeds when the forward reaction is complete".* This misconception may result in the learners' difficulty in understanding how both reactions occur simultaneously at equilibrium. That Jane could identify the source of this learner's confusion demonstrates an improvement of both the PPST's reasoning ability and understanding of the important concepts of Chemical Equilibrium that the learners need to understand.

Jane further said that *"the relationship of the concentrations of reactants and products to one another is reflected in the equilibrium constant".* This idea emphasizes that concentrations of reactants and products at equilibrium are not equal, thus removing the misconception that the

learner might have had with regard to this concept. The inclusion of "equilibrium constant" in the statement highlights the PPST's recognition of the importance of using a representation to explain and expand on it. It was because of Jane's ability to identify with learner prior knowledge and ability to deal with the learner doubt in her response, using two other components of TSPCK that she was awarded 3, the developing level of understanding and reasoning ability. The TSPCK map enclosed in Figure 5.6 highlights a pictorial summary of interactions between the components of TSPCK as seen in Jane's reasoning in the post-test response.

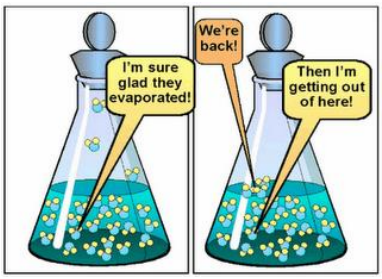


Learner misconceptions explained in a tutorial presentation

Jane and her partner, Sara, demonstrated an even deeper understanding and reasoning during the tutorial presentation on this aspect of attempting to rectify learner misconceptions. This was seen in their explanation that contained a coherent interactive use of four TSPCK components, with one of those components repeating. The explanation made was in response to a common learner misconception that ***no reaction occurs at equilibrium***. The following explanation was made as a way of redressing the misconception:

"Say for example, I have water. I have four water molecules, neh (demonstrates using ball and socket models), in a closed system because chemical equilibrium occurs in a closed system. So, what will happen is that as the reaction progresses, it will be in such a way that the first water molecule will change its state from liquid to gas. The second one becomes a gas. So, now equilibrium has been reached. But the reaction is still constantly taking place. So as one gaseous molecule of water condenses, and becomes a liquid, at the same time or at the same rate, this liquid molecule of water will evaporate to form the gaseous form of water. So, what will happen is that when you have two molecules that are gases at the same time, you have two molecules of water that are liquid.…. So, these things will happen at the same rates, but when you look at it, it appears as though nothing is happening. So, when this forms the other forms (repeats 3 times). So, to you when you are looking at it as a student, it looks as though nothing is happening but there is a reaction that is constantly taking place at the same rates basically. The forward reaction happens

at the same rate as the reverse one. So, when you are looking at it, it seems as if nothing is happening, but a reaction is constantly taking place. So, as you can see here these are getting tired of being in a liquid form. Then they rise and form a gas. But then at the same time, when that happens, when the equilibrium is achieved, the gaseous form of water would form a liquid and some of these here would also form a gas…"



In this explanation, four components of TSPCK are interactively used in an interwoven fashion as the PPSTs presented a conceptual strategy that they could use to rectify the misconception that the learners have around the reactions that have reached the state of chemical equilibrium. In this explanation, the use of **representations** appears to center the instructional strategy and sequencing. Emphasis is then made on the necessary condition for Chemical Equilibrium to be reached, ensuring that the system is closed (**demonstrative of aspects of curricular saliency).** The explanation proceeds with the explanation of what happens as water changes phase from liquid to gas and back to liquid explicitly pointing out that the two processes occur simultaneously. This brings forth the aspect of **learner prior knowledge,** removing the idea that the learners have with respect to the reactions at equilibrium. The forth component of **"what is difficult to understand"** surfaces as emphasis was made on why the learners might think that there is no reaction at equilibrium because, microscopically, it appears as if no reaction is taking place. The last component on representations is seen repeating in this episode. The interwoven interactive nature of the components is in the order R/CS/LPK/WD.

Development in Curricular Saliency-(CS): *a high-level jump*

Aspects of curricular saliency involve the teachers' aptitude for identifying what is core and peripheral to the topic; the important concepts that the learners would need to learn about the topic. Different researchers have shown that the knowledge of content is the precursor (Pitjeng-Mosabala & Rollnick, 2018) or precondition (Neumann, Kind & Harms, 2018) to the development of knowledge for teaching (TSPCK) which is being investigated in this study. One could therefore argue that the PPSTs cannot identify the core concepts of the topic if their overall content knowledge of the topic is low.

In a TSPCK test, the PPSTs were requested to select three main ideas to be taught about chemical equilibrium from a list of the concepts provided (**see Figure 5.7**). They were then requested to draw a concept map that presented the main ideas and their corresponding subordinate concepts, all arranged in the order in which the teacher would want to present them to the learners.

CATEGORY B:

Questions 3.1 -3.4 relate to planning and sequencing of concepts.

3.1 What do you consider to be the **three main ideas** (main concepts) to be taught about equilibrium at Grade 12? Choose from the list provided.

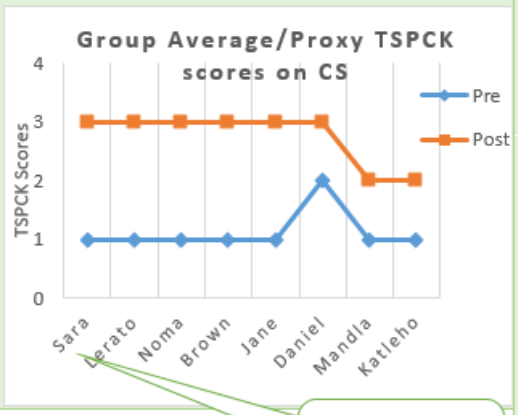
Dynamic equilibrium	Equilibrium constant
Chemical reactions	Rate of reaction
Lê Chatelier's principle	Equilibrium shift
Factors that affect equilibrium	Calculation of equilibrium concentrations
Open and closed systems	Homogeneous and Heterogeneous equilibrium
Physical equilibrium	Forward reaction and reverse reaction
Extent of reaction	Other

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

Figure 5. 7: An extract on curricular saliency from the TSPCK test on chemical equilibrium

For a closer look into how the scores were assigned, the extracts in **Figure 5.8** on the pre- and post-intervention tests on CS are used to explain how the PPSTs' knowledge and shifts in their TSPCK quality. These extracts are taken from the pre and post TSPCK test tools for Sara, one of the PPST participants whose TSPCK quality grew remarkably throughout all the components. The data obtained from the CoRe are used as supplementary data to the TSPCK tests. All these data combined are used to describe Sara's development and improvement in the component of CS across the intervention.

TSPCK Score



Scored 1 and 3 in pre and post-tests respectively

Reason for sequencing

Serves as a foundation for the topic to be taught after (Acids and Bases). The way the big ideas are formulated and sequenced is in such a way that the level of complexity increased from differentiating what open and closed systems are for example; Basically defining what chemical equilibrium is and what is required to achieve it, followed by the factors affecting it, to calculations and finally stopping at real life applications serving as proof that it is of use.

Pre- test extract

Three main ideas and Sequence

Factors affecting equilibrium
Le Chatelier's principal
Chemical reactions

Concept map

Chemical reactions	Le Chatelier's	Factors affecting equilibrium
• Open & closed systems • Dynamic and physical equilibrium • Homogeneous and heterogeneous equilibrium	• Calculations of equilibrium concentrations •Equilibrium constant • Extent of reaction	• Equilibrium shift • Rate of reaction • Applications of chemical equilibrium

Reason for sequencing

It is a foundation for the section coming/taught after (Acids and Bases). Students are initially taught on what a closed and open system is, then advance to Le Chatelier's (with calculations) increasing the level of complexity of the topic, and then close of with what affects equilibrium position and the applications of chemical equilibrium

Post-test extract

Three main ideas and Sequence

Dynamic equilibrium
Factors that affect equilibrium
Calculation of equilibrium concentrations

Concept map

Dynamic equilibrium	Factors affecting equilibrium	Calculation of equilibrium concentration
• Open & closed system • Forward and reverse reaction (equilibrium & rates) •Homogeneous & heterogeneous equilibrium • Physical equilibrium • Reversibility & reactions that go to completion	•Le Chatelier's principle • Equilibrium shift	• Equilibrium constant (Kc) • Equilibrium quotient (Q)

Figure 5. 8: Sara's responses in the pre (post) TSPCK tests in the component of curricular saliency

On the pre-TSPCK test, Sara was not able to identify, correctly, the three main ideas of the topic: Chemical Equilibrium. The identified concepts are the *"Factors affecting equilibrium, Le Chatelier's principle and Chemical reactions"*. These concepts are a mix of the main ideas and subordinate concepts. For example, the Le Chatelier's principle is subordinate to the "factors that affect the Chemical Equilibrium "whilst the concept of "chemical reactions" is not part of the topic, Chemical Equilibrium. Chemical reactions can however be thought of as a topic that should be taught prior to the teaching of Chemical Equilibrium. This is because the knowledge of how chemical reactions occur will be required for understanding the Chemical Equilibrium. In this case, the sequence is of no use because of a mix of concepts. As it was explained earlier, the concept of CS talks to the teacher's ability to identify what is core and peripheral to the topic (Mavhunga, 2014). It reflects their understanding of important concepts within the topic which, when grasped, leads to the understanding of the topic. The identification of the main or Big Ideas reflects such understanding. However, in the pre-test Sara demonstrated a low level of TSPCK quality in this aspect, thus scoring as low as 1, a limited proficiency score.

At post-intervention, Sara scored a 3 which put her at a developing level. In her post-test, Sara was able to correctly identify three main ideas for this topic: *(i) Dynamic equilibrium, (ii) Factors that affect equilibrium and (iii) the Calculations of equilibrium constant.* One of the main ideas, *"factors affecting chemical equilibrium*" is seen in both pre and post-tests responses. The difference that can be highlighted about this main idea, as per the pre and post-test, is sequencing. In the pre-test, Sara suggested teaching the concept after the discussion of chemical equilibrium constant calculations. The sequence was reversed in the post-test where the calculations of equilibrium constant were done after discussing the factors that affect chemical equilibrium. Sara scored a 3 in this component. Apart from being able to identify the big ideas of the topic and their subordinates, she also arranged all of them in a logical sequence in such a way that they built onto each other. When asked about the choice of the sequence, she responded:

"… serves as a foundation for the topic to be taught after (Acids and Bases). The way the big ideas are formulated and sequenced is in such a way that the level of complexity increased from differentiating what open and closed systems are for example, basically, defining what chemical equilibrium is and what is required to achieve it, followed by the factors affecting it, to calculations and finally stopping at real life applications serving as proof that it is of use".

The sequence in which the concepts are arranged and presented is an essential teaching element. This assists with a smooth transition between concepts, such as when content is organized either from easy/simpler to difficult/more complex. Furthermore, Sara's reasoning of the choice of sequence referred to not only the conceptual scaffolding but also the understanding of other topics. Current research in chemistry education also alluded to the correct sequencing which makes the conceptual understanding of the topic possible (Sibanda, 2018).

Sara's response to the CoRe on Curricular Saliency (CS) component

In the CoRe, the Big Ideas were self-formulated. The CS component has multiple prompts. The first prompt is based on the formulation of Big Ideas, followed by the important concepts that need to be covered under each identified main idea. Also important in the presentation of these Big Ideas and their subordinate concepts is their arrangement in a sequence in which they would be taught in the classroom. The following Big Ideas were presented by Sara in her post CoRe: *"(i) Chemical Equilibrium is a* ***dynamic*** *process that will only take place in a closed system; (ii) Chemical Equilibrium position in a closed system can be* ***shift by external factors*** *including concentration, temperature and pressure; (iii) The* ***ratio of concentration of products to reactants*** *can be quantified at equilibrium (constant at a constant temperature)".* Conveniently so, the core concepts identified on the CoRe were similar to those on the post TSPCK test, although the CoRe was more detailed as it required PPSTs to generate a meaningful statement from the main concept, hence the name "Big Ideas" used to refer to those statements.

In both post CoRe and TSPCK test, Sara identified the aspect of reversibility of chemical reactions as important for Chemical Equilibrium to be possible. This was observed in the list of subordinate concepts under each of the main ideas. This concept was however not identified as important in the pre-intervention test. The aspect of reversibility is a particularly important condition for Chemical Equilibrium as this state cannot be attained in irreversible reactions. This is also fundamental to the understanding of the presence of forward and reverse reactions happening simultaneously and at the same rate when a reaction has reached an equilibrium state, hence the dynamic nature of Chemical Equilibrium.

Development in use of representations-(R): *a high-level jump*

This section discusses the PPSTs' pre- and post-intervention score shift in the component of TSPCK that involves the use of representations. **Figure 5.9** presents the pre- and post-intervention TSPCK extracts by Lerato on the use of representations. In this component of TSPCK, Lerato experienced an improvement in TSPCK proficiency from 1 to 3 after an exposure to the intervention. The qualitative aspects of reasoning that led to the scores obtained by Lerato are presented below.

In this section of the use of representations in the TSPCK test, the PPSTs were provided with a list of representations that could be used in the teaching of dynamic and static equilibrium. From this list, they were requested to select the best representation that they thought would be used to efficiently address the concept of Chemical Equilibrium. Their selection of the representation was followed by a detailed elaboration of how the representation would be used in their teaching of the concept. The use of representations is essential in chemistry. It enables the content to be transformed and emphasized into a form that the learners can efficiently comprehend. The rubric in Appendix F presents, in detail, how the conclusion to the scores was reached. In the pre-test Lerato selected the representations without any detail of how they would be used to explain the concepts *static* and *dynamic* equilibrium. This is what awarded him a score of 1, indicating his limited ability in the use of representations.

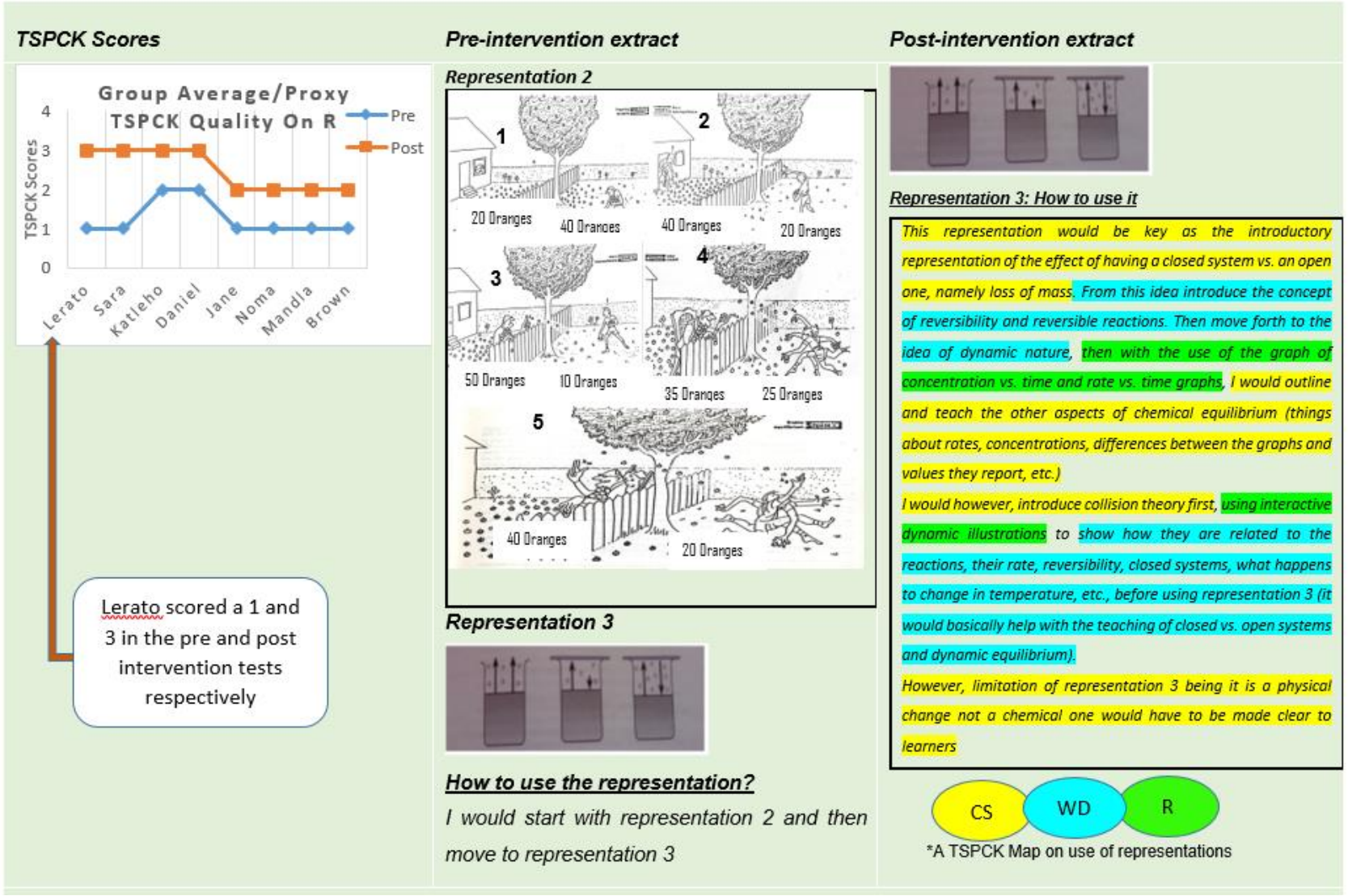


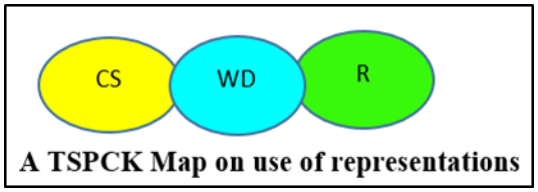
Figure 5. 9: Lerato's responses in the pre-post TSPCK tests in the component of representations

As demonstrated in **Figure 5.9,** Lerato's response on the pre-intervention test on how he planned to use the representation that he thought works best is brief. He only shows that he would use representation 2 followed by representation 3. Lack of explanatory notes to explain how the representations would be used, which concepts would be explained and what role each of the representations would play in the presentation of the concepts led to the score of 1. This response shows a limited knowledge and competence to use representations at this stage.

Post the intervention, Lerato's response had more depth with a much clearer perspective and explanation of the selected representation. Important to highlight in this response is his value of sequencing throughout the explanation. The post-intervention extract displays the use of multiple representations to explain concepts. To begin with, he argued that he would use some dynamic illustrations to introduce the concept of collision theory. He argued that the illustration would show*" how they are related to the reactions, their rate, reversibility, closed systems…"* This statement shows that he understands the importance of knowing which concepts should come prior to teaching the topic, which, if not understood by the learners could make the topic difficult to understand. Emphasis on collision theory is followed by the use of representation 3 to differentiate between an open and a closed system. As he argues, *"this representation would be the key as an introductory representation of the effect of having a closed system v. an open one, namely loss of mass".* Following this, the concept of reversibility is brought to the fore and discussed, then the dynamic nature of equilibrium is also discussed. The concept of the reversibility of chemical reactions as well as the dynamic nature of chemical equilibrium are the concepts referred to in research as difficult to understand. The use of representation 3, suggested by Lerato, could make the concepts accessible to the learners since reversible reactions happen in closed, secluded systems in order to prevent the loss of mass and energy, as demonstrated in his response above.

"Then with the use of the graph of concentration vs. time and rate vs. time graphs…. I would outline and teach the other aspects of chemical equilibrium (things about rates, concentrations, differences between the graphs and values they report, etc.)". The use of these graphs could remove learners' misconception about the concentrations of the reactants and products at equilibrium as well as the rates of forward and reverse reactions which simultaneously take place at the same rate, thus addressing learner misconception concerning the dynamic nature of Chemical Equilibrium.

Lerato was awarded a 3 in this post-test section after the intervention because his reasoning to the selection and application of the representations included reference to two more TSPCK components, mainly the aspects of curricular saliency (CS) and concepts that are difficult to understand (WD). The TSPCK map, also presented in Figure 5.9, summarizes the PPST's explanation given in response to the use of representations to teach about the concepts regarding Chemical Equilibrium:



A TSPCK Map on use of representations

The map presented above was generated from the explanation that Lerato gave on how he would go about using representations to teach the concepts of Chemical Equilibrium, mainly dynamic equilibrium. As presented in this map, the explanation begins with emphasis on the concepts that are being addressed, *this representation would be the key as the introductory representation of the effect of having a closed system vs. an open one, namely the loss of mass*. This is followed by the introduction of reversibility, a concept identified in research as difficult to understand as explained in the previous sections, ... *introduce the concept of reversibility and reversible reactions. Then move forth to the idea of dynamic nature.* Lerato further introduces the use of graphs, *including the use of the graph of concentration vs. time and rate vs. time graphs,* to expand and emphasize the concept. The explanation continues with Lerato moving back and forth between the components as he expands on how the representations would be used. This explanation demonstrates an interwoven interactive use of TSPCK components, all used with the purpose of making the concepts of chemical equilibrium explicit and comprehensible. An observation has been made from Lerato's description in this extract. He devised a conceptual teaching strategy using curricular saliency and representations to address an aspect that is difficult for the learners to understand.

Response to the CoRe

Lerato's increased knowledge and understanding of the use of multiple representations interactively with other components to explain a particular aspect is also seen in his response to the CoRe, post the intervention. One of the prompts on the CoRe, having presented the Big Ideas and subordinates to the main concepts included identifying/presenting different representations to use in one's teaching of those concepts. This could include representations used to teach the concepts that cause learner misconceptions, as well as those considered as difficult for the learners to efficiently comprehend. Lerato suggested the use of the following representations to teach aspects related to the dynamic nature of equilibrium:

- Subatomic interactive simulations of collision theory, closed vs. open system, and reversible reactions.
- Pictures or a video of a closed and an open pot boiling to initiate conversation on the difference between open and closed systems.
- Chemical equation notation for **reversible reaction** i.e. **double arrows** in equations.

Looking at the list of the suggested representations, it can be noted that the PPST wished to use more than one type of representation for each concept of the content. For example, both a subatomic simulation (microscopic representations) and a video or pictures are suggested for use in the teaching of an aspect of closed and open systems, whilst simulations and symbolic representations are suggested for emphasis in the teaching of reversible reactions. The use of multiple representations, as was emphasised during the intervention,was also observed in Lerato's response on the post-intervention test. His ability to use more than one representations in his explanation of the concepts is identified as a quality of good teaching in chemistry. The main issue here is using multiple representaions and analogies interactively with other components to produce a meaningful understanding of a concept. In this sugested list of representations, emphasis is put on important concepts, including those that are difficult to understand.This brings an interaction between at least 3 components of TSPCK, thus categorizing it at a developing level of proficiency.

Although half of the PPSTs had their scores increasing to a developing level after the intervention, it is also only in this component where more PPSTs (half of the group) scored at a basic level after the intervention. With half of the group scoring at a developing category after the intervention,

half of the class remains at a not so fascinating score of 2 after the intervention, categorized at a basic TSPCK proficiency. It could be argued that for this particular component, the PPSTs still needed some improvement. Their use of multiple representations in an interactive manner with other components is therefore questionable, as the score of 2 indicates the ability of the PPSTs to interactively use the maximum of two components of TSPCK in their reasoning. Although their scores were not necessarily high, those PPSTs did experience a shift in TSPCK quality after the intervention in this component. Because the study was looking at the PPST's average and proxy score, an average of 2.5 was obtained for this component, classifying the score at a developing level when 2.5 is rounded up to a proxy average of 3.

The use of representations is of utmost importance in science, as it assists with the explanation of concepts by bringing forth the visual aspect nature of the content. This includes the use of analogies, demonstrations, models, diagrams, metaphors etc., all of which make explicit the content of the subject matter in order to enhance accessibility by the learners. In chemistry specifically, researchers adhere to the use of three types/levels of representations: macroscopic, sub-microscopic and symbolic representations. It is because of the abstract nature of chemistry as a subject that researchers consider the use of multiple representations in the teaching of concepts useful in helping the learners to understand concepts more meaningfully. The teachers' efficiency of using more than one type/level of representation in their reasoning and teaching assists with conceptual transformation and increases the chances of accessibility by learners. Overall, therefore, the pre-service teachers' ability to use multiple representations in their reasoning improved from the limited to the developing level after the intervention.

Development in what is difficult-WD: *One category shift*

This section discusses the average shift in the pre-post intervention scores and hence quality in the component of TSPCK, what is difficult to teach. In this component of TSPCK, the PPSTs experienced an average of one quality jump. The PPSTs' pre-test score average was 2. An increase of one quality jump landed the PPSTs' average score at 3, a developing category. The graph in **Figure 5.10** summarizes the average pre-post intervention scores of one of the PPSTs on the component, what is difficult to teach (WD). Evident in this graph is that there is an improvement in the scores of seven PPSTs after the intervention. Six of the 7 PPSTs had their scores increasing

from 2 to 3 whilst one of them scored a massive 4, placing him at an exemplary level after the intervention. Only one of the 8 PPSTs participating in this study did not experience any improvement in this component after the intervention.

Figure 5.10 presents pre- and post-intervention extracts from Daniel on a component of what is difficult to understand **(WD).** Complementary to the TSPCK tests are Daniel's CoRe and tutorial responses on what is difficult to understand. Daniel is one PPST who experienced a massive change in this category, scoring at an exemplary level in this component after the intervention (see the extracts below).

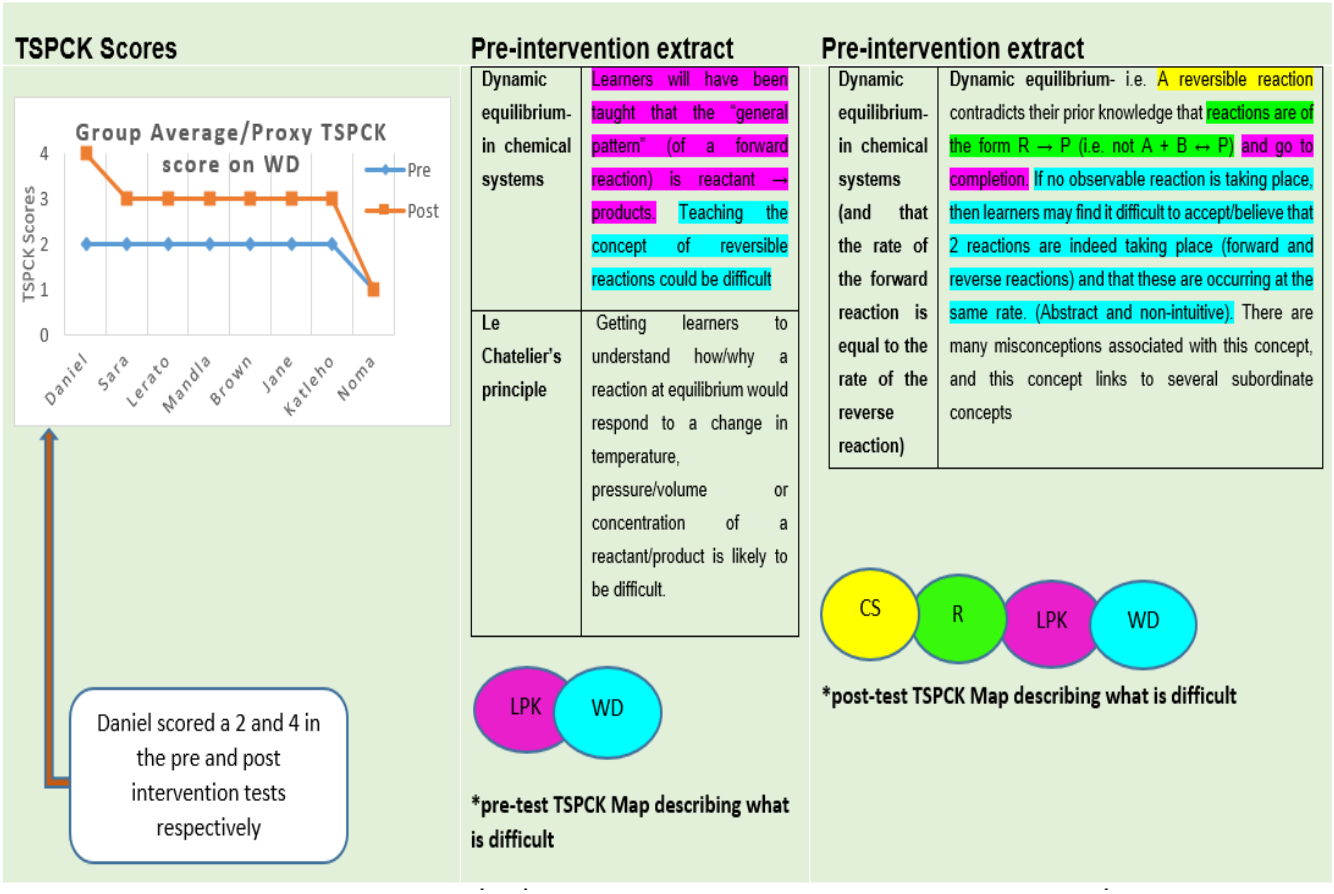


Figure 5.10: Daniel's responses in the pre (post) TSPCK tests in the component of what is difficult to understand/teach.

In this section of what is difficult to understand (WD), the test requested that teachers select from the given list of concepts, those that they considered difficult to understand. Daniel scored 2 on a pre-intervention test. He selected two concepts which he considered difficult to teach and understand but one of those was common in the pre- and post-test responses, the concept of

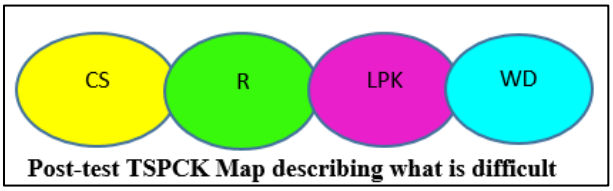
dynamic equilibrium, as presented in **Figure 5.10**. Daniel refers to the impact that the previously learned content could have in the understanding of the concept of dynamic equilibrium; "*Learners will have been taught that the "general pattern" (of a forward reaction) is reactant → products"*. This explanation demonstrates Daniel's acknowledgement of the learner's prior knowledge (LPK) which, in this case, contributes to the difficulty in understanding a concept of reversibility in dynamic equilibrium where the learners believe that reactions go to completion. The second component talks to the misapplication of the Le Chatelier's principle, also a common learner misconception. The concept of Le Chatelier's by Daniel also talks more on the core concepts, as shown in this extract. He said, "*getting learners to understand how/why a reaction at equilibrium would respond to a change in temperature, pressure/volume or concentration of a reactant/product is likely to be difficult"*. This sentence also highlights, slightly, the concepts that contribute to the difficulty. In this context, Daniel scored 2, a basic score, because his reasoning of the difficulties identified drew on only one other TSPCK component which is the learners' prior knowledge (LPK). Furthermore, even though Daniel was able to identify the gate keeping concepts, he does not explain the reasons leading to the difficulty of the concepts.

Daniel selected five concepts as difficult to teach in the post-test. The concepts are a combination of content/subject matter knowledge of the topic, including the calculations involved which draw back on learner prior knowledge. These were *(i) open and closed system, (ii) calculations of concentrations vs. calculations of moles, (iii) working with the equilibrium constant in calculations, just a number with no units, (iv) using mathematical ratios in a chemical concept, and (v) dynamic equilibrium-in chemical systems*. A concept of dynamic equilibrium mentioned in both pre and post-tests as a difficult concept is a very crucial and important concept to understand in this topic which requires explicit emphasis and clarity. Daniel even expanded on the concept of dynamic equilibrium by adding the concept of explaining that "the rate of the forward reaction is equal to the rate of reverse reaction". A much clearer and detailed reasoning was given to explain why that concept is difficult to teach, as indicated in this post-test extract:

"Dynamic equilibrium- i.e., a reversible reaction contradicts their prior knowledge that reactions are of the form R → P (i.e., not A + B ↔ P) and go to completion. If no observable reaction is taking place, then the learners may find it difficult to accept/believe that 2 reactions are indeed taking place (forward and reverse reactions) and that these are occurring at the same rate,

(abstract and non-intuitive). There are many misconceptions associated with this concept which link to several subordinate concepts".

This reason provides, in detail, the gate keeping concepts that when not fully understood could add to the difficulty of the dynamic nature of equilibrium. The explanation involves the recognition of the learners' prior knowledge and an emphasis through the use of a symbolic representation on why understanding the concept could be compromised, as seen in the statement: *a reversible reaction contradicts their prior knowledge that reactions are of the form* $R \rightarrow P$ *(i.e., not* $A + B \leftrightarrow P$*) and go to completion.*



Post-test TSPCK Map describing what is difficult

The TSPCK map above illustrates pictorially, the interaction and interplay between different components of content knowledge transformation used by Daniel as he explained why/how teaching the dynamic nature of equilibrium is not easy to do. Four components of TSPCK are used interactively as he explains what causes the difficulty in teaching and understanding of dynamic equilibrium. First, he brings to the fore which concept is important in discussing the aspect of dynamic equilibrium-reversibility, thus highlighting the aspect of **curricular saliency-CS.** A symbolic representation is then shown explaining the learners' prior knowledge about reactions with an arrow suggesting that reactions go to completion instead of a double headed arrow to represent reversibility of reactions. Two components of TSPCK are evident in this explanation, the use of **Representations-R** and **learner prior knowledge-LPK.** The concept of learner prior knowledge is seen where the PPST indicates that the learners think reactions go to completion because of a single headed arrow that they are exposed to when they are first introduced to the idea of chemical reaction/equations. Research has also confirmed this as a misconception that the learners have about chemical reactions, whereby they belief that reactions go to completion. The explanation given by Daniel ends with him explaining in more detail what is **difficult to understand about reversibility-WD.** It is because of the interactive nature of these components that Daniel scored an exemplary 4 in this aspect.

Daniel's response to the tutorial and the CoRe

The reason for the difficulty of the concept on dynamic equilibrium is emphasized by Daniel throughout the intervention project, with the reasoning becoming more detailed and thorough than it was on the pre-test that was completed before the intervention commenced. During the tutorial session, Daniel presented: *"I suspect that learners will find the concept of 'dynamic equilibrium' difficult to understand because it contradicts their existing schema: that R → P (reactions are not reversible and go to completion). If no observable reaction is taking place, learners may find it difficult to understand that two reactions (forward and reverse reactions) are occurring at the same rate".*

A more impressive response which contributes to and qualifies the score of 4 awarded to Daniel in this component was also observed in the exemplary reasoning he gave on the CoRe response: *"I consider it difficult to teach that the reaction continues in both the forward and reverse directions – simultaneously, because learners will only have their prior knowledge (up until this point, learners have been taught that all reactions are of the form reactants → products), i.e. reactions are not reversible and always go to completion. That a reaction does not go to completion and is reversible (and therefore dynamic) is difficult to understand".* The reasoning in the CoRe and the tutorial is explicit, clear and easy to follow. Knowing what causes learner difficulties around a concept is essential; as this enables the teacher to develop instructional strategies and source out representations that would assist with teaching the content in as explicit manner as possible, maximizing its accessibility by the learners.

Development in the component of conceptual teaching strategies-(CTS): *a one category shift*

The discussion in this section focuses on the shift in the average scores obtained in the components of conceptual teaching strategies. In this component, the PPSTs' TSPCK development averaged to 1 TSPCK quality jump from 2 to 3, as presented in **Table 5.1.** The graph in **Figure 5.12** summarizes the individual pre- and post-intervention scores by the PPSTs on the conceptual teaching strategy (CTS) component of TSPCK. This presents the pre-, post-intervention shift in scores for the PPSTs on CTS. Three of the 7 PPST participants experienced a 2-quality jump in this category from 1-a limited TSPCK level to 3. a developing category. Two PPSTs, Katleho and Lerato, had a 1 quality jump, from category 2 to 3, the developing category. Sara's score before and after the intervention remained at a developing category level, scoring 3 in both tests. One

PPST however, experienced a decrease in quality TSPCK proficiency in this component. Noma started with a score of 3 at a developing proficiency of TSPCK before the intervention and yet landed at a lower category, 2 after the intervention.

Figure 5.12 presents the extracts with the aim of explaining the shift in quality TSPCK of one of the PPSTs, Mandla. First, the extract presented in **Figure 5.11** was taken from the Chemical Equilibrium TSPCK tool that the PPSTs responded to with respect to the component, conceptual teaching strategy (CTS). The PPSTs had to use a given learner response to devise a teaching strategy for teaching the topic content on "predicting the effect of factors that disturb the equilibrium". The PPSTs were expected to use the response given by the learner, based on the question asked, as follows *"what is the effect of adding more water to the reaction given"?* See extract below:

CATEGORY D:

Le Châtelier's' Principle

6. Following below is a student's written response in a class test designed to assess prior knowledge of students about Le Châtelier's' Principle.

Question:

What is the effect of adding more water to reaction given below at equilibrium?

$$CH_3CO_2H(aq) + H_2O\ (l) \rightleftharpoons CH_3CO_2^-\ (aq) + H_3O^+(aq)$$

A student responded:

'More $CH_3CO_2^-$ (aq) and H_3O^+ (aq) will be formed, to counter act the effect of adding more water to the reactants. This will happen until a new equilibrium is reached'.

Following the student's response, how will you teach a lesson on predicting the effect of factors disturbing the equilibrium?

Figure 5. 11: An extract on conceptual teaching strategies from the TSPCK test on chemical equilibrium

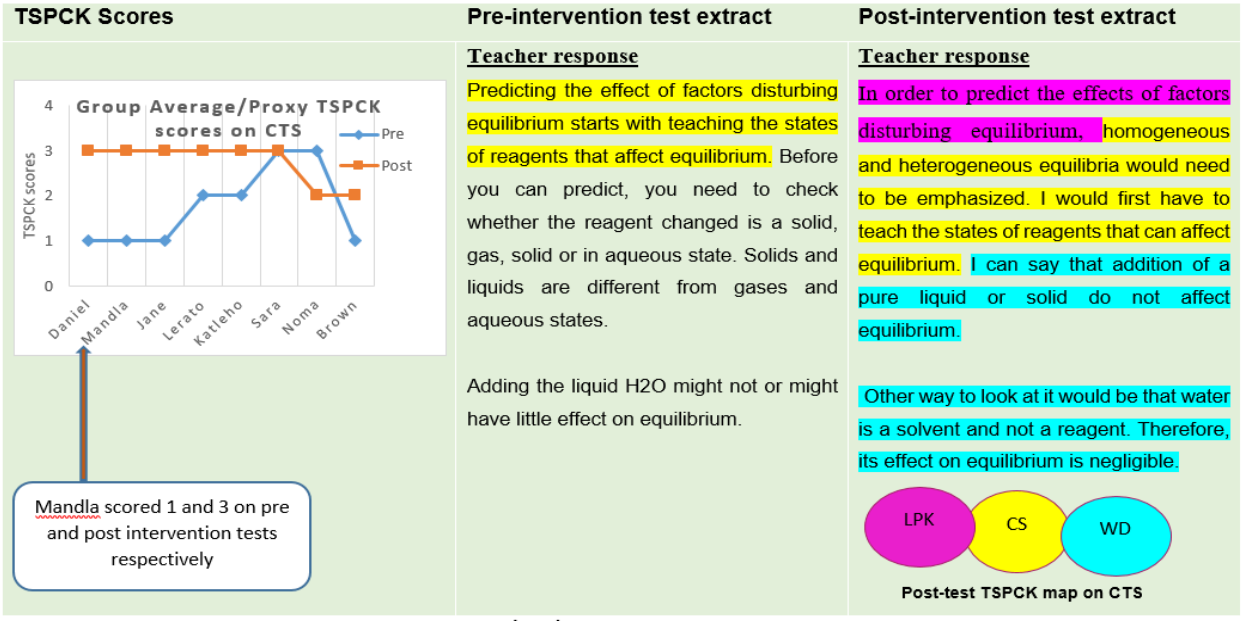
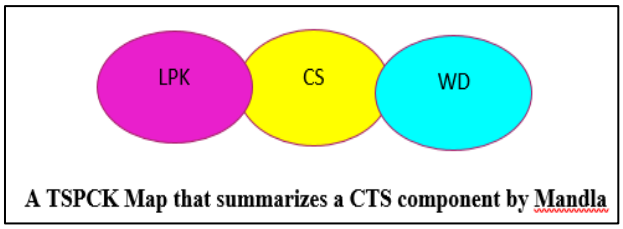


Figure 5. 12: Mandla's responses in the pre (post) TSPCK tests in the component of conceptual teaching strategies

Mandla's response on the pre-intervention test scored him 1 because of his limited ability in coming up with a strategy that would help him teach the concept on the effect of disturbance at equilibrium. Even though he begins by indicating what needs to be taught first before discussing the effect of the disturbance, the response leaves us hanging, with the PPST not clearly indicating how he would end up explaining the concept to the learners. For example, Mandla wrote in his response; *"before you can predict, you need to check whether the reagent changed is a solid, gas, solid or an aqueous state. Solids and liquids are different from gases and aqueous states".* The sentence that follows gives a sense that Mandla is not sure about how water would affect the state of equilibrium of this reaction: "*adding the liquid H_2O might not or might have little effect on equilibrium".* This indicates the PPST's lack of an aspect of curricular saliency (CS) or that he might hold the same misconception as the learner with respect to the effect of adding a pure liquid to a reaction at equilibrium. With limited subject matter knowledge of the topic, explaining it to the learners would be a more complex occurrence. This is why Mandla scored 1 in this first attempt.

The post-test, however, gave a complete turn on Mandla's response, landing him to a developing category with a score of 3. He argued that *"in order to predict the effects of factors disturbing equilibrium, homogeneous and heterogeneous equilibria would need to be emphasized. I would*

first have to teach the states of reagents that can affect equilibrium". Knowing which concepts need to be taught first indicates the PPST's value of aspects of curricular saliency **(CS)** which also talks to the importance of choosing the correct sequence that when followed can enhance learner understanding of the concepts. Furthermore, Mandla argued that to explain this further, he would make learners aware that "*addition of a pure liquid or solid does not affect equilibrium".* This explanation gives a sense of improvement in terms of content knowledge and hence aspects of curricular saliency by Mandla, since in the pre-test response, he was not sure how water would affect equilibrium. Highlighting that liquids and solids do not affect equilibrium also shows that the PPST might be aware of the learners' misconception **(LPK)** that liquids and solids affect equilibrium constant, the misapplication of the Le Chatelier's principle. Teaching this concept has also been proved by research as difficult **(WD)** because the Le Chatelier's principle states, as highlighted in the learner response *"addition of a reactive/disturbance to a reaction at equilibrium will cause a reaction to respond in a way that counteracts the effect of change"* which in this reaction involves addition of water. This therefore makes it difficult for learners to predict the shift because the principle has some exceptions. Knowing when to apply the principle and where it does not apply makes the prediction a bit tricky for the learners, especially where liquids such as water are involved. The PPST's response demonstrates an improved understanding of the gate-keeping concepts that when not understood will lead to the learners thinking every reactive has an effect on reactions that have reached equilibrium. Whereas the learners need to know that there are some exceptions to the rule. A TSPCK Map is used to demonstrate the response by Mandla post the intervention.



A TSPCK Map that summarizes a CTS component by Mandla

To teach this concept, Mandla emphasizes the aspects of curricular saliency (CS), to address learner misconceptions with regard to the concept of Le Chatelier's principle, a concept also identified as difficult for the learners to understand. Mandla scored at a developing TSPCK proficiency level because his conceptual teaching strategy shows an interaction and interplay of 3 TSPCK components.

5.1.2b. TSPCK development shift across all the components: *shift by one teacher*

This section shows the best practices that came in each component. It gives a sense of quality TSPCK development for one PPST. The qualitative reasoning by one of the PPSTs, Sara, is presented to explain her overall TSPCK development across all the components. Her profile is presented in Figure 5.13.

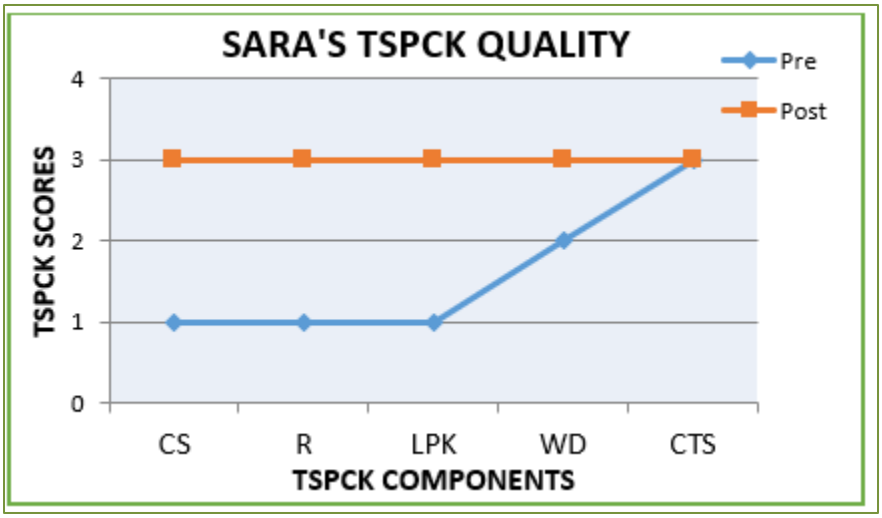


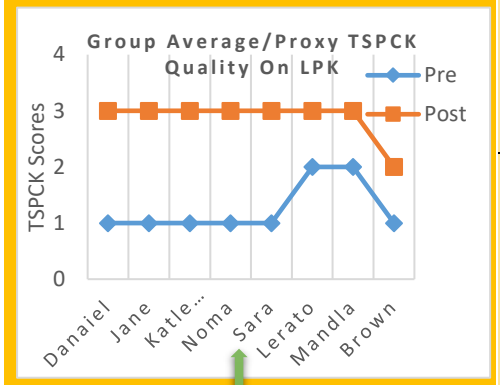
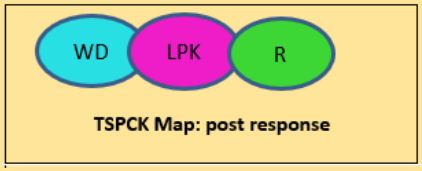
Figure 5. 13: Sara's planned TSPCK profile on Chemical Equilibrium

Sara obtained a 2-category jump in two TSPCK components, CS and the use of representations (R) from a limited score to a developing TSPCK proficiency after the intervention. In the two other components, LPK and WD, Sara experienced a 1 category jump from a basic score to a developing score after the intervention. On the last component of CTS, though, there seems to be no development, Sara's score was at a developing proficiency level before and after the intervention. Sara experienced a high level TSPCK shift across the components, scoring at a remarkable developing proficiency throughout.

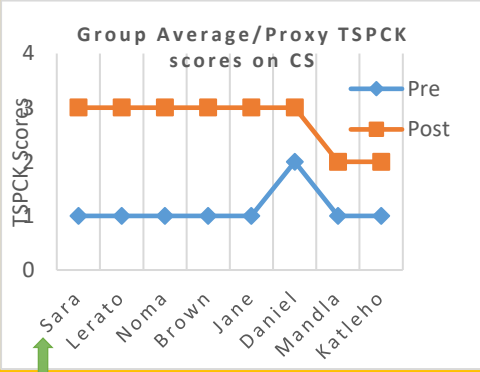
Sara's TSPCK development across the intervention

This section discusses the findings of the overall development of TSPCK quality for one of the PPSTs, Sara. This analysis makes the overall growth in all TSPCK components of a single PPST evident; to demonstrate the general PPST's TSPCK development. Sara's qualitative reasoning presented in the pre- and post-intervention TSPCK tests is used to explain the scores that she obtained through the adapted TSPCK rubric.

An important reminder to note is that even though the discussion below presents Sara's performance in each component, the criteria in the TSPCK rubric calls for the interaction of each of the components with others (see Appendix F).

TSPCK Score	Pre-test extract	Post-test extract
Learner prior knowledge including misconceptions  Sara scored 1 in the pre-test and 3 in the post-test on the component of Learner Prior Knowledge including misconceptions	When you have a chemical reaction, sometimes you need more reactants to make a certain product or vice versa. Therefore, for chemical equilibrium it is the rate of forward and reverse reaction that is of interest where both need to be occurring at the same rate. Therefore, the same amount of product and reactant are being formed. **About the extract** In the above extract, the teacher is responding to the learner response that said, "concentrations of reactants and products at equilibrium are equal". The explanation that the teacher gave however seems a bit vague. Even though she appeared to have identified the misconception, her explanation does not explicitly address what the learner said. The response however portrayed Sara's misconception as she indicated in her last sentence above that the *"same amount of product and reactant are being formed"* at equilibrium. It is because of this that her reasoning was considered as limited-hence scored 1.	The two reactions, forward and reverse reactions happen simultaneously. For a chemical reaction to be at equilibrium, the rate of the forward reaction must always be equal to the rate of the reverse reaction. Having said that, for equilibrium to be achieved, the concentration of the reactants and products must remain constant which is another characteristic of a reaction that is at equilibrium **(WD).** The concentrations of reactants and products at equilibrium must not necessarily be equal (although it is possible that they can be) but should remain constant **(LPK).** Perhaps the graphs of concentration vs. time and rate vs. time will help explain the difference between equal rate and constant concentrations **(R).** **About the extract** Sara was scored 3 for the response given in this extract. To address the misconception that the learner had, she begins by explicitly putting emphasis on what happens at equilibrium; that reactions occur simultaneously and rates and not concentrations are equal, whilst concentrations are constant; a concept that learners find difficult (WD). Sara also addresses another possible misconception on concentrations of reagents at equilibrium (LPK). She then suggests the use of graphs as representations (R) to emphasize her explanation of what is equal at equilibrium. Three components of TSPCK are therefore seen working interactively together as she explains this concept. These are what is difficult to understand (WD), learner prior knowledge (LPK), and use of representations (R).  **TSPCK Map: post response**

Curriculum saliency



Sara scored 1 in the pre-test and a 3 in the post TSPCK test on the concepts related to curriculum saliency.

Three main ideas and Sequence

Factors affecting equilibrium
Le Chatelier's principal
Chemical reactions

Concept map

Chemical reactions	Le Chatelier's	Factors affectir equilibrium
● Open & closed systems ● Dynamic and physical equilibrium ●Homogeneous and heterogeneous equilibrium.	● Calculations of equilibrium concentrations ● Equilibrium constant ● Extent of reaction	● Equilibrium shift ● Rate of reaction ● Applications of chemical equilibrium

Reason for sequencing

It is a foundation for the section coming/taught after (Acids and Bases). Students are initially taught on what a closed and open system is, then advance to Le Chatelier's (with calculations) increasing the level of complexity of the topic, and then close of with what affects equilibrium position and the applications of chemical equilibrium.

About the extract

Of the three concepts identified above, only one (Factors affecting equilibrium) qualify as a main concept; the second one is a subordinate, whilst the first concept (chemical reactions) is not part of chemical equilibrium. It should be discussed in a different topic. Inability to identify important concepts of the topic is what determined the score of 1 at this stage.

Three main ideas and Sequence

Dynamic equilibrium
Factors that affect equilibrium
Calculation of equilibrium concentrations

Concept map

Dynamic equilibrium	Factors affecting equilibrium	Calculation of equilibrium concentration
● Open & closed system ● Forward and reverse reaction (equilibrium & rates) ● Homogeneous & heterogeneous equilibrium ● Physical equilibrium ● Reversibility & reactions that go to completion	● Le Chatelier's principle ● Equilibrium shift	● Equilibrium constant (Kc) ● Equilibrium quotient (Q)

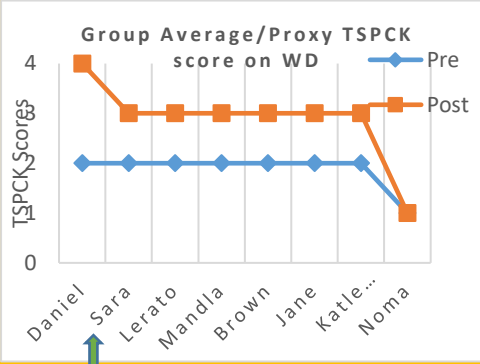
Reason for sequencing

Serves as a foundation for the topic to be taught after (Acids and Bases). The way the big ideas are formulated and sequenced is in such a way that the level of complexity increased from differentiating what open and closed systems are for example, basically defining what chemical equilibrium is and what is required to achieve it, followed by the factors affecting it, to calculations and finally stopping at real life applications serving as proof that it is of use.

About the extract

Post-intervention, Sara was able to identify and provide a logical sequence of the important concepts of the topic and the necessary subordinates for each big idea. This demonstrated an improvement and development as opposed to her response before the intervention. Sara's reason for importance of sequencing of the concepts in the order above is seen to include/highlight the idea of conceptual scaffolding/sequential development of understanding for a specified topic (Acids and Bases). Her reasoning and understanding of what is important for learners to know in this topic is what led to her score of 3.

What makes the topic difficult



Sara scored 2 and 3 on the pre and post TSPCK tests respectively on what is difficult to understand.

The calculation of concentration using the (RICE) **r**atio/ **I**nitial/ **C**oncentration/ **E**quilibrium Table	✓	Not necessarily teaching but since it is a new way calculating concentration students might make mistakes along the way when calculating concentrations (more mathematical errors)
Calculations of concentrations vs. calculations of moles	✓	N=m/M Kc=[Products]/[Reactants Concentration is not the number of moles as starting point but they can help find the other. Mole also dependent on the number in front of th chemical substance (e.g., MgO)
Using mathematical ratios in a chemical concept	✓	Maths is an issue. Some students are not able to move around numbers without defying the rules of maths (e.g., ratios that are or divided

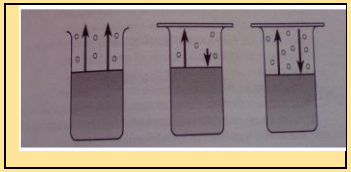
About the extract

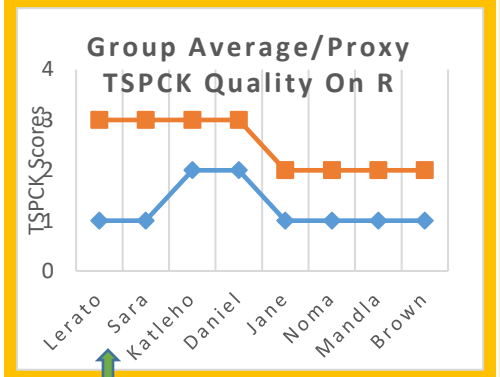
The concepts identified by Sara above are mainly calculation-based. Most of what is considered as difficult to teach and negatively impacts on learners' understanding of the topic considerably, links back to their prior knowledge and lack of understanding of mathematical calculations. In the pre-test, Sara could not identity aspects of subject matter knowledge (on the topic chemical equilibrium) that could contribute to the difficulty of the topic. Sara was scored 2 because she was only

The calculation of concentration using the (RICE) **r**atio/ **I**nitial/ **C**oncentration/ **E**quilibrium Table	✓	Mathematical errors are usually what scare students in this case
Calculations of concentrations vs. calculations of moles	✓	Students do not acknowledge that amount can be called number of moles also and that concentration is thereafter calculated from number of moles or a backward calculation from concentration to moles can be done despite formulae being provided. N=m/M. C=n/v. Students also fail to understand that the number of moles can be used to calculate equilibrium constants and that it is only concentrations that are used
Dynamic equilibrium – in chemical systems	✓	In most chemical reactions after reaching chemical equilibrium, no macroscopic reaction seems to be taking place, so perhaps using microscopic analogies is best
Equal rates vs. equal concentrations at dynamic equilibrium	✓	English is of essence here. Perhaps students mostly confuse the concentration vs. time graph with the rate vs. time graph which aid in differentiating between equal rate and constant concentrations at equilibrium
Factors affecting equilibrium	✓	A catalyst does not affect equilibrium position rather it is related to the rate of a reaction (how fast a reaction proceeds)- confuse reaction rate with chemical equilibrium
Differentiating between equilibrium constant and quotient	✓	Students confuse Q with Kc, although the formula remains unchanged, Kc is strictly for a reaction that is at an undisturbed equilibrium whereas Q is before equilibrium is achieved or after it has been disturbed.

About the extract

Even though Sara still considers mathematical knowledge as contributing to the difficulty of the topic, she was also able to identify aspects of subject matter knowledge that if not understood add to the difficulty of the topic. For example, the dynamic nature of equilibrium has been identified by research as one concept difficult to understand because at a macroscopic level, students cannot see any change happening in a reaction vessel. So, students fail to understand unless

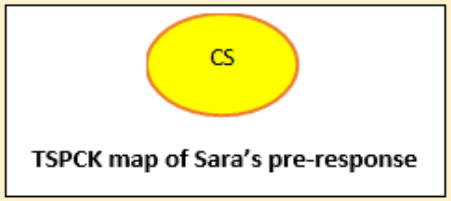
	able to relate learner difficulty to their prior knowledge (linked directly to mathematical struggles). 	other representations such at microscopic and symbolic levels are used to explain this concept. More subject matter content also contributing to this difficulty as presented above is the reversibility of the reaction as learners' prior knowledge mostly introduces them to the idea of reactions in one direction only. The ability of Sara to identify what might not be easy for students is particularly important as it will enable her to devise a strategy of teaching the concept so that learners can efficiently comprehend. This is why she scored a 3. Note: Reference to the third component would have scored her 4 instead.
Representations	I would ask that students group themselves and demonstrate an open and closed system as a starter. I would then show students the difference between static and dynamic equilibrium using water **(CS)** which is available everywhere (cheap even). Before I started the lesson, I would have asked students to tell me the difference between static and dynamic from what they know and use that as a basis for explaining the difference between the two in science. **About the extract** In the above extract, Sara shows that she would demonstrate to students the difference between an open and a closed system, as well as the difference between static and dynamic equilibrium. This explanation brings in the aspect of curricular	As an introduction to what chemical equilibrium is, I would rather do an experiment to demonstrate to students what I talk of (even let students do it themselves) showing what the difference between an open and closed system is to begin with. I would then show students the difference between static and dynamic equilibrium using water **(CS)** which is cheap and readily available, as the representations show highlighting the differences where for dynamic equilibrium, they will notice condensation on the top of the slide that closes the beaker **(R).** The reaction continuously taking place as the water droplets evaporate and condense seen by the little droplets moving down the side of the beaker (reversible)…. **(WD).** This representation is one of my most loved as it does not just help in explaining one subordinate idea but a variety. To make sure that students understood what I was teaching, I would give them an informal activity that we will all mark together in a class. **About the extract** Sara begins with a demonstration of core concepts "the difference between and open and a closed system". A closed beaker containing water is used to demonstrate the concept of dynamic equilibrium which brings forth the



Sara scored 1 and 3 on the pre- and post-intervention tests respectively on the use of representations

saliency as the teacher presents the important concepts that will be demonstrated to the learners in that lesson.

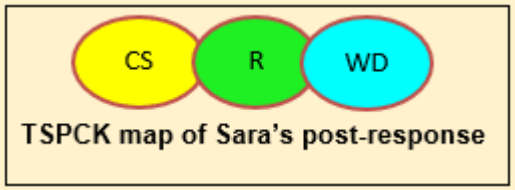
Presence of one TSPCK components in this extract, with no emphasis/clarity of how the representation would be used is what led to the score of 1.



TSPCK map of Sara's pre-response

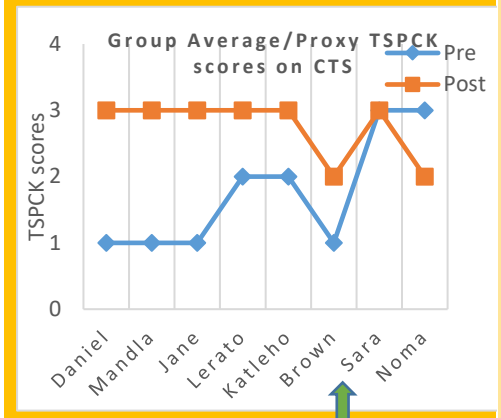
second component of TSPCK; curricular saliency. This is followed by the teacher's emphasis of what will be observed in the closed beaker after some time. This explains a concept considered difficult for students to understand which is that at equilibrium, the two reactions (forward and reverse) are still happening. Thus, even though it appears as though the reaction has stopped when equilibrium is attained, the two reactions are still happening. It has not stopped. This also helps to erase a misconception that a backward reaction only starts when all or the reactants are used up.

Even though four TSPCK components are seen used interactively in Sara's explanation above, she could not score a 4 because she did not acknowledge that this demonstration is a physical process which demonstrates phase change not a chemical reaction. She also settled with use of one type of representation (macroscopic type), whereas chemistry suggests that teachers use multiple representations in their explanations to help learners understand concepts. For example, use of symbolic and macroscopic representations could have come in handy, helping with emphasis of this concept.

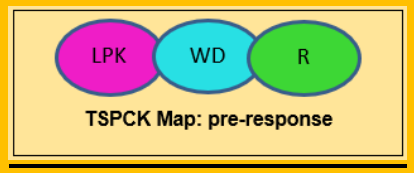


TSPCK map of Sara's post-response

Conceptual teaching strategies



Sara scored a 3 in both the pre-and post-intervention TSPCK tests.



So, it seems as if the student has good prior knowledge on this topic and is able to see how adding more reactant shifts the equilibrium position and how this affects reactants and products.

I would first list the various factors affecting equilibrium and ask that students tell me how they think equilibrium will be affected. From each response I get per factor I will try and correct the wrongs/misconceptions and lead students to the correct result of what each disturbance does to the equilibrium position

Students should always constantly refer to the definition of Le Chatelier's to aid them to predict what each disturbance does.

It would be nice to at least do one analogy of a factor affecting equilibrium (e.g., change in surface area/temperature) and students would then be able to see what that does to the equilibrium, and how its counteracted and restored

About the extract

The extract above scored Sara at a developing level of TSPCK quality. In the first statement made, Sara acknowledges the learner prior knowledge of the concept which she would use to identify existing learner misconceptions. She is also observed highlighting the importance of acknowledging the concept of Le Chatelier's principle to help with their prediction of the effect of the disturbance, a concept proved difficult to understand through research, using an analogy to explain the effect of least one disturbance.

It was because of the interplay of the three TSPCK components with use of one type of representation that Sara's score was at a developing TSPCK category.

As a starting basis I would ask different students to tell me the various factors that affect equilibrium and for them to tell me what the change in these factors will affect the equilibrium position. From the responses I get from this group of students I will get a sense of the misconceptions the students hold and use this to correct them and put emphasis on what is correct when I teach.

I also noted that the student did not recognize Le Chatelier's principle in their response, perhaps I would encourage students to make reference to him when they tackle questions pertaining to factors affecting equilibrium.

It would be great if I do an experiment (not everybody/student so as to save time), involving the reaction mentioned above to show students how one of the factors affecting the equilibrium position (e.g., change in concentration of reactives) will shift the equilibrium position which students will see through a change in color (pink ↔ blue.

About the extract

Similar to the pre-test intervention strategy, Sara acknowledged learner prior knowledge, explains the importance of remembering the concept Le Châtelier's when determining the effect of a disturbance, followed by an analogy that explains the effect of change in concentration of a reactive for a reaction that has reached equilibrium.

The use of three TSPCK components, categorized Sara's explanation at a developing TSPCK level of proficiency.



Figure 5. 14: Sara's TSPCK development in the five content knowledge transformation components across the intervention

As presented in Figure 5.14, Sara experienced a great development in all the components of TSPCK. With the TSPCK proficiency level at a developing level, from mostly a limited proficiency in about three components of TSPCK (LPK, CS and R), this development is encouraging. The intervention has thus proved effective in improving the PPSTs' reasoning about their content in this topic of intervention across the components. The PPSTs' improvement is not only observed in their pedagogical reasoning of the topic but also in their subject content knowledge of the topic itself. An example of subject matter knowledge can be highlighted in the PPSTs' response with regard to the component of curricular saliency (CS). If the PPST's knowledge of subject matter is limited, it will be challenging to know which aspects of the topic are important and core to the topic. If the PPST does not know what is core within the topic, he/she is unlikely to even know learner misconceptions with regard to the topic, which concepts might be difficult to comprehend and thus require more emphasis in the classroom as well as which representations might be necessary in helping with the explanations of specific concepts. The PPSTs' minimal subject matter knowledge also limits their choice and development of instructional strategies that provide efficient delivery of their content in the classroom.

On the other hand, seeing such a development in Sara and other PPST participants with regard to curricular saliency makes it easier for an improvement in other components to occur as well. Although CS does not necessarily talk to content knowledge but talks to what is peripheral and core to the topic, the lack of content knowledge may deny one the ability to know what is core and what is peripheral. This is why a PPST needs to be cognizant of the subject matter if he or she is to teach it to the learners. They might not necessarily be masters of the content, but lack of content altogether implies that they will encounter some challenges in the classroom.

Conclusion

The main purpose of this chapter has been to confirm the impact of the explicit intervention on TSPCK in improving the quality of TSPCK in chemical equilibrium for the PGCE class of 2018, a total of 8 PPSTs. This special group of PPSTs was exposed to an intervention on content knowledge transformation which aimed at developing their pedagogical knowledge on a chemistry topic, Chemical Equilibrium. The analysis in this chapter aimed at discussing the shifts in PPSTs' planned TSPCK across the intervention, as these are reflected in their change in achievement scores. Data analysis began with quantitative analysis of pre- and post- TSPCK tests to determine

the teachers' TSPCK proficiency. The scores obtained were then described using the PPSTs' qualitative responses from the tests, using data from the CoRes and tutorial discussions as complementary data. The use of multiple data sources ensures for data reliability and congruency when positively collaborated. Noticeable shifts were observed in the PPSTs' individual TSPCK quality. Improvements were also noted in the shifts in the quality of the individual components. The group experienced an improvement across all the components of knowledge transformation, thus experiencing a high-quality jump across all the components.

This improvement in the TSPCK quality for the PPSTs, individually and as a group, was anticipated, as it was highlighted earlier in the chapter. Some empirical studies (Mavhunga& Rollnick 2013; Mavhunga 2014) revealed the positive effect of the intervention on the PSTs' TSPCK development. However, they were focused on the undergraduate students. Even though this might appear to be the repetition of those studies, this chapter was evident and important in ensuring the credibility and reliability of the intervention itself. The results act as a credible baseline for the findings on the remaining data analyzed in Chapters 6, 7 and 8, as the findings indicate growth in the quality of TSPCK despite the duration on the exposure to other pedagogies.

The main purpose of this study was to find out how the PPSTs translate the TSPCK acquired in planning to teach science from an intervention, into enactment and the ultimate impact of this intervention on the learner achievement. The interest was on how their TSPCK in action looks or as it surfaces in their actual classroom teaching and its impact on learner outcomes. Even though this chapter may not necessarily address the main purpose of this study, the findings will act as a baseline of reference for the subsequent chapters which address the main research question more explicitly.

CHAPTER 6

ANALYSIS OF PGCE PRE-SERVICE TEACHERS' ENACTED TSPCK

The previous chapter determined the impact of the explicit intervention on the PPSTs' planned TSPCK in chemical equilibrium. The findings from chapter 5 provided a baseline of reference for this chapter which analyses the PPSTs' enacted TSPCK as they taught the concepts of chemical equilibrium to high school learners. This chapter describes how the PPSTs' planned TSPCK translates into the actual classroom teaching context on teaching the same topic of intervention. In order to do this, an analysis began with the transcription of the video recorded lessons into texts. The identification of TSPCK episodes followed. These episodes were then described to determine the extent of the interactions between the TSPCK components and mapped to pictorially display and describe the interconnectedness of the components in an episode. Finally, a comparison between the PPSTs' planned and enacted TSPCK quality with reference to their TSPCK scores was made.

6.0. Introduction

The main purpose of this study was to track how the PPSTs translate their personal TSPCK (pTSPCK) acquired in planning to teach (plTSPCK) into classroom context (enacted TSPCK) and its ultimate impact on learner achievement. With PCK described as tacit, according to Aydeniz and Kirbulut (2014) and Baxter and Lederman (1999), it is best to explain it by looking at not only what teachers know about teaching a topic usually observed in their planning to teachbut also their classroom enactment. In alignment with the authors, the previous chapter, Chapter 5, focused on presenting the quality of PPSTs' pTSPCK from the context of planning to teach Chemical Equilibrium. This chapter presents the analysis of the quality of their TSPCK, as observed in classroom enactment. The study refers to TSPCK in classroom enactment, in alignment with the Revised Consensus Model of PCK (RCM) (Carlson & Daehler, 2019) as eTSPCK.

This chapter discusses a subset sample of 3 PPSTs' pTSPCK that manifested in the actual classroom context. Their classroom practice provided a platform to witness and capture how their planned TSPCK on the topic of intervention translated into TSPCK in action. The 3 PPSTs are regarded each as a mini case from a cohort of 8 PPSTs that had registered for the physical science PGCE programmes. As referred to in chapter 3, each of the 3 PPSTs had to teach two main concepts of Chemical Equilibrium: (i) conditions for Chemical Equilibrium to be achieved and (ii)

the factors that affect the Chemical Equilibrium state. None of the 3 PPSTs had taught Chemical Equilibrium before, so this was their first experience teaching the topic. Without any experience on teaching this topic, the PPSTs' pTSPCK developed from a collective TSPCK learned through the intervention on the same topic which was probably the major reference point for their planning of the lesson and actual teaching of the lesson. Table 6.1 provides summarized information about the PPSTs.

Table 6. 1: The participants personal TSPCK and years of obtaining previous degree

PGCE Pre-service teacher	Sex	Personal TSPCK in planning (pTSPCK)		Previous Science degree	Years past out of school and out of work in the field
		Pre-test	Post-test		
Noma	Female	1	2	BSc Chemical Science	13
Sara	Female	2	3	BSc Honors	0
Lerato	Male	2	3	(Geochemistry) BSc Chemistry with Chemical Engineering	0

Note: Pseudonyms have been used to identify the PPSTs. Years past out of school and work refers to years of not using content learned in school.

Table 6.1 shows that all the 3 PPSTs had their previous bachelor's degrees in aspects of chemistry. The last column of Table 6.1 shows the PPSTs' number of years since obtaining the last degree in science and the years of not using that content if working. Noma had graduated 13 years prior to registering in the PGCE programme. She had also been working in the private sector for 12 years without using the content acquired from her bachelor's degree. On the other hand, Sara and Lerato had graduated one year prior to registering for the course. The description of the analysis of the eTSPCK follows.

6.1. Analysis

To analyze for the PPSTs' eTSPCK, the video recordings of the observed lessons were first transcribed verbatim. The analysis involved identification of TSPCK episodes from the transcribed data and the actual video records. The TSPCK episodes are described according to Park and Chen's (2012) PCK episodes where the teacher's explanation that portrayed the interplay between two or more TSPCK components (Mavhunga, 2018) is considered as a TSPCK episode. The study further drew on the data from the PPSTs' lesson plans and stimulated recall interviews to corroborate the findings and thus ensure reliability and validity of the findings. An analysis of their enacted lessons is checked against their lesson plans for similarities. This also allows the study to explain how that

which was planned translated into enactment, by comparing their TSPCK reflected in their lesson plans and the TSPCK in action.

6.1.1. A detailed description of the analysis

With the assistance from two independent raters, the videos were played several times to identify the moments that resembled the presence of TSPCK episodes. The next step of the analysis involved the identification of the TSPCK components within the identified episodes and the sequence in which they emerged. The description of the nature of the identified episodes follows (Mavhunga, 2015). The identified episodes are then presented pictorially, using the TSPCK Maps similar to Park and Chen's (2012). The TSPCK Maps, as used in this chapter, are a way of visually representing the teaching episodes extracted from the teachers' lesson presentations. These Maps pictorially display the sequence and the interactive manner in which the components of TSPCK merge in a teaching segment. The TSPCK episodes analyzed through the TSPCK Maps are then scored, using a peer validated rubric designed specifically for classifying the TSPCK episodes into categories of TSPCK quality with the focus mainly on the number of interacting components described in Chapter 3 (Miheso, 2018). The 3-criterion eTSPCK rubric categorized the emerging episodes into basic, proficient and sophisticated TSPCK levels.

6.2. Understanding the pre-service teachers' enacted TSPCK (eTSPCK)

6.2.1. Overview of the lessons by the subset of 3 PPSTs

This section presents an overview of the lessons delivered by each of the 3 PPSTs. These overview descriptions provide some context through which the findings may be received. A more detailed analysis of each lesson is provided later in the Chapter.

Noma's case

Table 6. 2: A general context for Noma's lessons

Content discussed in the lessons	Grade	Male	Female
1. Conditions for chemical equilibrium. 2. Factors affecting a chemical reaction that has reached a state of chemical equilibrium.	12	7 47%	8 53%

Noma had a class of 15 grade 12 learners. Seven (47%) of her learners were male and eight (53%) were female. Her first lesson which lasted 60 minutes was based on the conditions necessary for

Chemical Equilibrium (42 minutes) and she introduced factors the affect Chemical Equilibrium in the remaining 18 minutes. The second lesson was a continuation on the factors affecting Chemical Equilibrium which continued for 60 more minutes.

To introduce the lesson, she began by reviewing the learners' understanding and knowledge of chemical reactions and their features. The review included a highlight on the fact that some reactions give off heat (exothermic reactions) whilst others absorb heat (endothermic reactions) in order to be effective. In order to introduce the types of systems, she then asked the learners where the reactions usually take place. An open and a closed beaker were used to demonstrate the types of systems and the concept of reversibility. This was done with an example of a closed beaker, using a scenario of water changing phase from liquid to water vapor and back into liquid water; a continuous process which does not stop. The rate time graph was used to emphasize the rates of forward and reverse reactions being equal at Chemical Equilibrium and an explanation of why the reaction is said to be dynamic. She ended this discussion by explaining the nature of concentrations or reactants and products at Chemical Equilibrium, using the concentration versus time graph to emphasize.

This discussion began with a basic TSPCK episode followed by clusters of 2-sophisticated TSPCK episodes, 2-proficient and 1-basic episode.

The discussion went on to the factors that affect Chemical Equilibrium, concentration, pressure and temperature which were discussed in this same order. The effect of each factor was exhaustively explained using symbolic chemical reactions and concentration time graphs. The Le Châtelier's principle was used as an enabler guiding the thought about the effect of a disturbance to a chemical reaction that has reached a state of Chemical Equilibrium. The discussions constituted multiple TSPCK episodes (1-sophisticated, 4-proficient and 2-basic) all working together to help the learners to understand the concept.

Lerato's case

Table 6. 3: A general context for Lerato's lessons

Content discussed in the lessons	Grade	Male	Female
1. Conditions for chemical equilibrium. 2. Factors affecting a chemical reaction that has reached a state of chemical equilibrium.	12	7 50%	7 50%

Lerato's lesson was for 14 grade 12 learners. It had an equal number of both male and female learners, a total of seven (50%) each. His first lesson which only introduced the conditions for Chemical Equilibrium lasted for 60 minutes. The next 60 minutes focused on the factors that affect Chemical Equilibrium.

To introduce the first lesson, Lerato used the first 15 minutes laying a foundation for what chemical reactions entail. The discussion was based mainly on the collision theory, an important aspect that assists the learners to understand how reactions take place. This became the main anchor for both lessons 1 and 2, each consisting of 3 TSPCK episodes, two-proficient and one-basic. He then introduced open and closed systems using an analogy of boiling water in a closed versus an open pot. These preceded a discussion on reversibility of reactions on closed systems using the same analogy of boiling water and a video simulation for emphasis. Lerato also used the concentration versus time graph to explain the change in concentrations of reagents as well as the rates, before and until Chemical Equilibrium is achieved. The discussion on conditions for Chemical Equilibrium consisted of 4-sophisticated TSPCK episodes, 3-proficient and 2-basic episodes. Although Lerato discussed the rates of forward and reverse reactions in this lesson, the rate time graph was not mentioned or discussed until the second lesson.

In the second lesson, Lerato began the discussion with an evaluation of the previous lesson and then discussed the rate time graph and its relation and difference to concentration time graph. This was done in the first 20 minutes of the second lesson, in 4 TSPCK episodes; one-sophisticated, two-proficient and one-basic. The remaining 40 minutes were then dedicated to discussing the factors that affect Chemical Equilibrium in 7 TSPCK episodes; 3-sophisticated, 3-proficient and 1-basic episode. The lesson was then summarized in two TSPCK episodes where the second

episode dwelled on the use of the Le Chatelier's principle in determining the effect of a disturbance on a chemical reaction that has reached the state of Chemical Equilibrium.

Sara's case

Table 6. 4: A general context for Sara's lessons

Content discussed in the lessons	Grade	Male	Female
1. Conditions for chemical equilibrium. 2. Factors affecting a chemical reaction that has reached a state of chemical equilibrium.	12	9 64%	5 36%

Sara's lessons consisted of 14 grade 12 learners. Nine (64%) of the learners were male and five (36%) were female. Sara dedicated her first lesson to the conditions that are necessary for Chemical Equilibrium. This topic extended into the second lesson, taking the first 30 minutes of the lesson to finalize the explanation on the concept.

Sara began the first lesson by checking the learners' understanding of the concept of Chemical Equilibrium, before stating the objectives of the two lessons. The discussion then led to a differentiation between reversible and irreversible reactions, followed by that on closed systems, which are a condition for reversibility. Symbolic chemical equations and an analogy of water changing phase were used to explain the reversible nature of reactions including the dynamic nature of Chemical Equilibrium. The rate and concentration time graphs, together with an analogy demonstration with a group of learners were also used to explain the nature of chemical reactions and concentrations of reactants and products at Chemical Equilibrium. This lesson was modeled into 5-sophisticated TSPCK episodes, 6-proficient and 3-basic episodes.

The first 30 minutes of the second lesson were based on the evaluation of the previous lesson. The factors that affect Chemical Equilibrium then proceeded for the remainder of the time. Because of the limited time that Sara had for this part of the lesson which manifested into 3-sophisticated and 2-proficient episodes, the effect caused by two factors, pressure and temperature, were not discussed.

It is worth pointing out that although the 3 PPSTs' lessons were based on the same concepts of Chemical Equilibrium, their approach to teaching the concepts differed from one PPST to another, highlighting the sophisticated and complex nature of the teaching process.

6.2.2. Overview of the Findings

All the video-recorded lessons for the 3 PPSTs' were analyzed for the quality of enacted TSPCK. The episodes identified from each PPST video-recorded lessons are presented below. The components in an episode are presented in the sequence in which they interacted in a teaching segment. Table 6.5 displays the overall patterns of TSPCK episodes identified from the 3 PPSTs' video-recorded lessons when teaching a topic of Chemical equilibrium. The episodes are depicted with shorthand notations of TSPCK components. This provides a holistic view of each of the PPSTs' TSPCK episodes and allows us to see how the components interact.

Table 6. 5: The nature of the TSPCK component interactions in the identified TSPCK episodes

TSPCK Episodes collected over a total of 120 minutes for each PPST			
PPST	**Basic/Simple**	**Proficient**	**Sophisticated**
Noma	R/CS LPK/CS CS/WDx2	WD/LPK/R R/LPK-WDx2 LPK/WD/R LPK-R/WD R/LPK/WD LPK-CS/R R/WD/LPK	LPK/R/CS/R LPK-R/CS/WD/R/LPK CS/LPK-CS/WD R/LPK-CS/WD
Lerato	R/CS CS/R CS/WD LPK-CS WD/R WD/CS	R/CS/WDx2 CS/R/LPK LPK-CS/R×2 CS/R/CS LPK-R/WD LPK-R/CS CS/WD/R R/LPK/WD	R/LPK-CS/WD/R CS/R-WD/LPK/CS WD-R/CS/LPK CS/WD/R/CS LPK/R/WD/LPK LPK-CS/R/WD LPK/CS/R/WD CS/R/LPK/R/WD WD/CS/LPK/R
Sara	CS/LPK×2 R/CS LPK/WD	R/LPK/WD WD/R/LPK LPK/R/WD CS/WD/LPK LPK-R/CS×2 LPK/R/CS LPK-R/WD×2 R/CS/WD	LPK/R/CS/R CS/LPK/R/LPK/WD LPK/CS-R/WD LPK/WD/R-R/LPK/CS/CTS LPK/R/WD/CS LPK/R/CS/LPK LPK-R-CTS/CS LPK-R/WD/CS CS/WD/LPK/CS CS/WD-CS/R/CTS LPK-WD/LPK-R/CS LPK/WD-CS/R

The first column shows the PPSTs' pseudonyms as used in this study. The successive columns display different categories of episodes identified per PPST, from the basic level which is demonstrated by an interaction between two TSPCK components; a proficient level which is signified by an interaction between three TSPCK components and finally, a sophisticated episode, evidenced by the presence of four or more components that interact in a distinguishable manner. All the episodes were scored using a 3-point scale validated TSPCK rubric (Miheso, 2018), designed specifically for measuring TSPCK in action.

A quick look into these PPSTs' TSPCK profiles in Table 6.5 reveals that the nature of component interactions varies for individual teachers. There is no specific pattern observed in the component interactions and the formed episodes. This makes the observed episodes discrete and particularly different from one another. It is similar to what has been revealed in the literature that the PCK component interactions are idiosyncratic (Aydin *et al.*, 2015). This idiosyncrasy of the interacting components shows the random nature of this process, hence the idiosyncrasy of the components

interacting, observable even when teaching the same concept. Most of the PPSTs episodes portray varying characteristics because of the nature of the component interactions.

Another important highlight from Table 6.5 is that the lessons by the 3 PPSTs are dominated by TSPCK episodes displaying an interweaving sequence of interacting components **(LPK/R/CS/R)** and those showing a combination of the two-sequencing fashion, linear and interweaving patterns **(LPK-R/CS/WD/R/LPK)**.

Also identifiable are the different two-way interactions between the TSPCK components (Aydin *et al*., 2015). Identification of these two-way component-component interactions makes it possible to determine the components that are central in the integrations. The quantity of component-component interactions and the frequency of interactions per individual TSPCK components were also found to differ from one PPST to another. Table 6.6 presents the frequency of component interactions from the identified episodes. The symbol (-), does not necessarily imply a linear interplay between components involved, but rather signifies a link between two components that were interacted within the identified episodes. The top part of the table on component-component interactions portrays different sets/pairs of possible interplays of different TSPCK components. The second part under the title "TSPCK component interaction frequency" provides a summary of the number of times a TSPCK component was used in the episode integrations.

Table 6. 6: The frequency of TSPCK component interactions in the identified TSPCK episodes

Component-component interactions across the 3 PPSTs' lessons				
Components interplay	**Sara**	**Lerato**	**Noma**	**Total**
CS-R	**11**	**16**	**13**	**40**
CS-LPK	**9**	**7**	**8**	**24**
R-WD	**8**	**12**	**8**	**28**
R-LPK	**19**	**9**	**7**	**35**
WD-LPK	9	3	3	15
TSPCK Component interaction frequency				
Component	Sara	Lerato	Noma	Total
CS	**29**	**32**	**28**	**89**
LPK	**37**	**19**	**18**	**74**
WD	**25**	**24**	**18**	**67**
R	**40**	**37**	**28**	**105**

Four two-way component interactions bolded in Table 6.3 are common across the PSTs episodes. The interplay between an aspect of curriculum saliency (CS) and that of representations (R), showing (CS-R) had the most appearances across the PPSTs TSPCK episodes. All the other components, however, were significantly involved in multiple integrations with the component of representation (R) receiving the most integrations comparatively, a total of 105 across the 3 PSTs lessons. The second element which was central in the integrations is an aspect of curriculum saliency (CS) with 89 appearances in the identified episodes.

The PPSTs' TSPCK profiles are further displayed in Figure 6.2. The charts provide a pictorial overview of the total number of episode types per PPST.

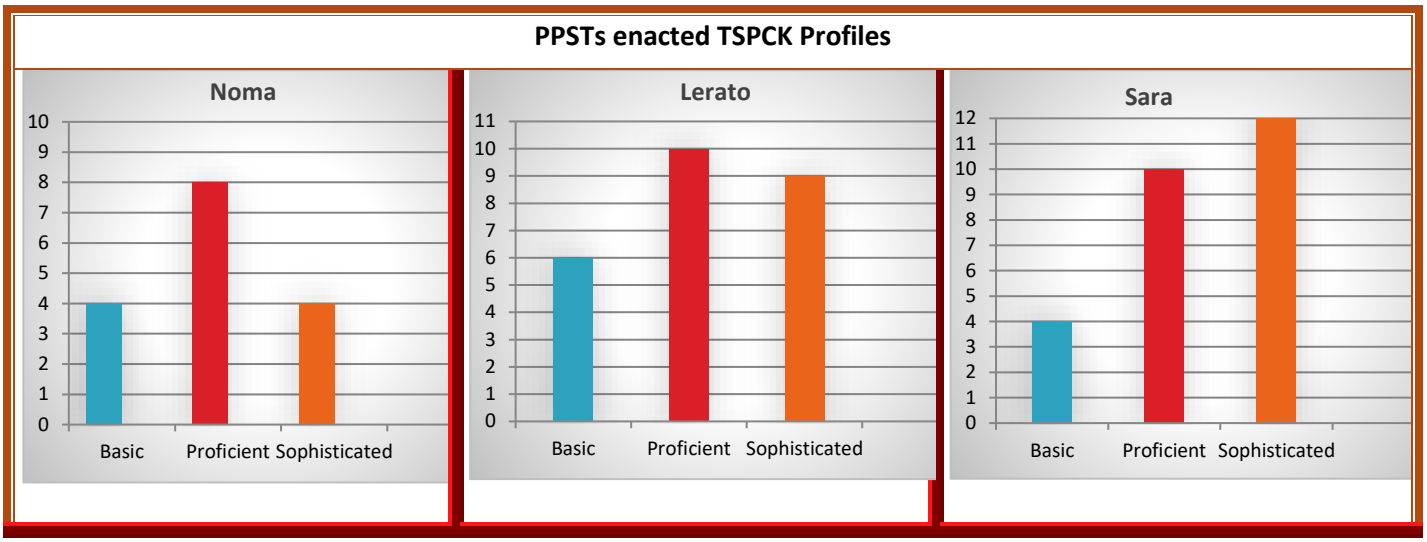


Figure 6. 1: The participants' action TSPCK profiles

Figure 6.2 shows that all the 3 PPSTs had higher proportions of TSPCK episodes graded between proficient and sophisticated levels. Their teaching was dominated by episodes that demonstrate and suggest high quality teaching because of an evident interaction of 3 and more TSPCK components in a teaching segment. Although Noma's TSPCK episodes were largely proficient (8 of the total 16), overall, her episodes were also predominantly of high quality with 4 of the remaining 8 TSPCK episodes categorized as sophisticated. On the other hand, Sara and Lerato's lessons had about the same number of proficient and sophisticated episodes spread across their teachings, 10 proficient and 8 sophisticated episodes for Lerato and 10 and 12 for Sara, respectively. Overall, Sara had the highest number of sophisticated episodes than everybody else. This raised the expectation that Sara gave good quality explanations because she was able to draw from multiple TSPCK components in her explanations of Chemical Equilibrium concepts.

It is, however, noted that looking at these episodes alone may not necessarily mean the lesson was of good quality. The issue rather is on what was done in a teaching segment, including how the components that interact are used to create a more comprehensible concept. Accordingly, the quality of the lesson lies in the logical working together of the interacting components. For example, some of the basic TSPCK episodes (even though they are classified as of low quality) may be used as ground preparation for high quality episodes (proficient and or sophisticated) that follow. This implies that the presence of basic TSPCK episodes may not necessarily mean a poor-quality lesson. Although, ideally, the presence of more proficient and sophisticated episodes in

one's lesson raises the expectations of possibilities of a lesson that is rich in explanations of high quality, that by itself does not necessarily imply a good lesson.

As quantity alone does not mean good quality, the idea of whether those components were working together to build depth into an explanation was worth a comprehensive analysis. Therefore, in order to get a sense of the nature of the lesson and its quality, we needed to put the teaching episodes in the sequence in which they happened. An in-depth analysis of each of the 3 PPST's lesson observations was exhaustively executed. The analysis displays the extracts of all the episodes identified within the lesson and presented in the exact order and time ranges in which they emerged. The section also provides a detailed qualitative analysis describing the nature of the lesson tasks from which the episodes emerged. An interpretation of each episode is presented opposite each segment. An in-depth analysis of Sara's lesson is provided below.

6.2.1. An in-depth analysis of the PPSTs' lessons

As alluded to in chapter 3, each observed PPST was considered as an individual mini case where each PPST's enacted TSPCK is checked against their planned TSPCK and learner achievement. Specific for this chapter, each of the subset of 3 PPSTs' enacted TSPCK is checked alongside his lesson plans and lesson reflections. This differs from the presentation in chapter 5, where comparisons between the PPSTs' quality of TSPCK was made.

To reiterate, the 3 PPSTs were observed teaching the key ideas on the topic of Chemical Equilibrium: *(i) the conditions necessary for Chemical Equilibrium to occur* was taught in the first lesson, and *(ii) the factors that affect Chemical Equilibrium* which was taught in the second lesson. In order to gain an insight into the lesson, there was need to develop the PPSTs' TSPCK profiles which looked at the episodes in the sequence in which they emerged. First, the analysis presented a pictorial map of the PPSTs' first lesson episodes. The maps which are in the form of a number line display a summary of the PPSTs' lesson episodes in a sequence in which they emerged in their teaching. This shows the patterns of their progression in the classroom action. Non-episode teaching segments are equally placed within the number lines. A number line is used to pictorially display the PPSTs' profile of TSPCK episodes in their respective lessons. In addition to the lesson observation number line episode presentations, the lesson plan episodes identified under the section of *sequencing and conceptual teaching strategies* are equally displayed and related to those

revealed in the actual lessons. This section of the lesson plan afforded an opportunity for the PSTs to expand on how they would teach a specific key concept in the classroom, where all the subordinate concepts are arranged in the order in which they wish to teach (Mavhunga, 2018).

Basic episodes are represented in these maps by blue dots, proficient episodes by red dots and the green dots for sophisticated episodes. Absence of an episode in a teaching segment excerpt is represented using the yellow dots.

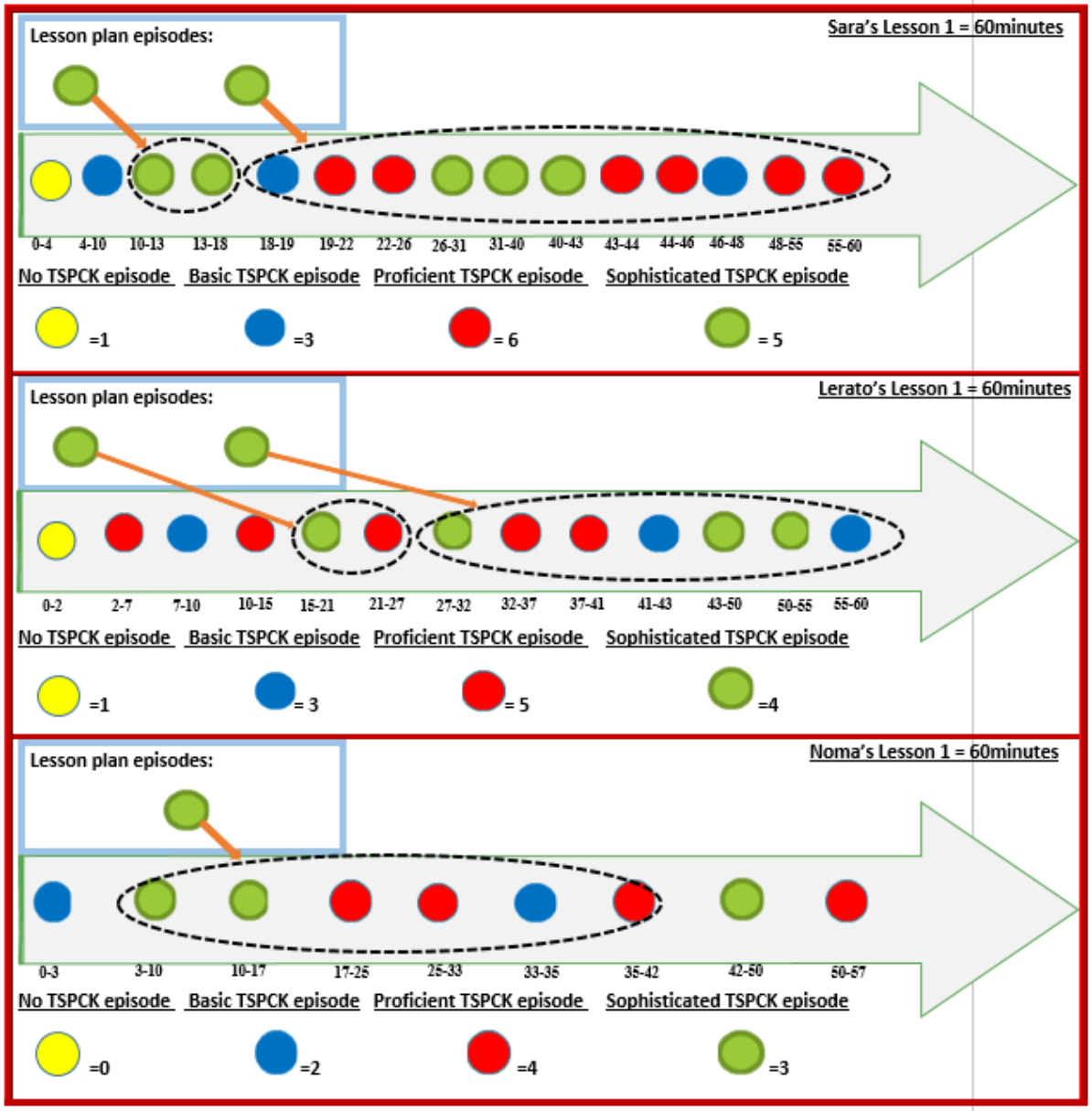


Figure 6. 2: A pictorial display of PSTs' TSPCK episodes in the sequence of their emergence

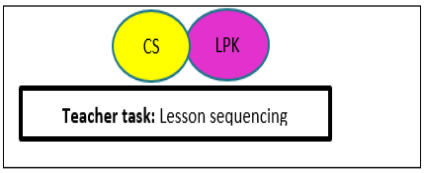
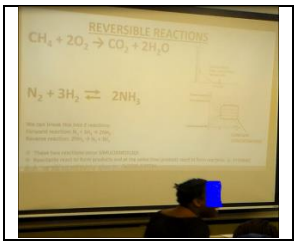
Figure 6.3 shows that the difference in the number of episodes identified from the PPSTs' lesson plans compared to what transpired in the classrooms is high. For example, two sophisticated TSPCK episodes on how Sara had planned to teach on the conditions necessary for Chemical Equilibrium were identified from her lesson plan. On the other hand, 11 episodes were portrayed in her lesson on explaining the exact main idea and then two more episodes that were triggered by learner questions. This is in line with the findings from the literature that enacted lessons are an expansion of the lesson plan resulting into clusters of episodes that still explain the same idea portrayed on the lesson plan (Mavhunga & van der Merwe, 2020). A single sophisticated TSPCK episode from the lesson plan, gave rise to a group of proficient and sophisticated TSPCK episodes enclosed within a bigger dotted ring.

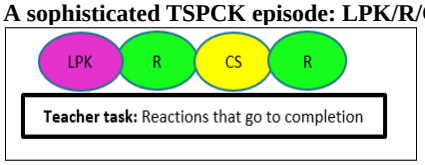
Due to the complex and tacit nature of ePCK and its associated eTSPCK which makes capturing it difficult, it was found necessary to do an in-depth analysis of the PPSTs' lesson observations, to gain an insight into how they materialized. This analysis, as referred to above, involved portraying the extracts of the lesson in the exact order of emergence in the classroom to get a picture of how explanations made built onto each other to give an overall understanding of the key concepts in Chemical Equilibrium. Sara's lesson which had the highest number of episodes of high-quality raised a bar of expectation that her teaching was good and dominated with high quality explanations. Her lesson was therefore worth exploring further. A step-by-step in-depth qualitative analysis of Sara's lesson is presented in Table 6.7 to show how the structure of her lesson, the nature of the explanations given, and the teaching strategies used may have contributed to the learners' conceptual understanding of the key ideas of the topic. Due to the limited space and the volume of analysis done for each lesson, Noma and Lerato's detailed lesson analysis are attached as Appendices R and S.

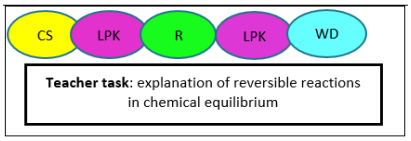
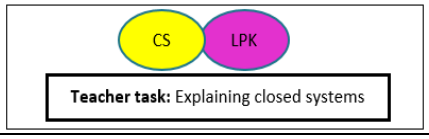
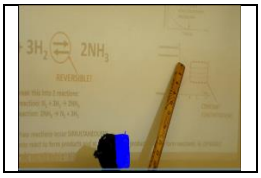
The first row in Table 6.7 pictorially presents Sara's TSPCK episodes in the sequence at which they emerged across the two lessons taught. A step-by-step analysis of the two lessons then follows, with the first column revealing the actual lesson excerpt. An interpretation of each teaching excerpt is presented opposite the teaching segment on the second column including a TSPCK map and a shorthand TSPCK sequence exhibited by the episode.

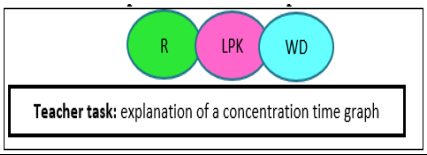
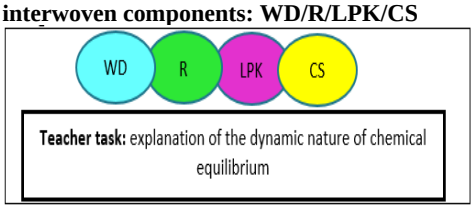
Table 6. 7: A detailed analysis of Sara's lesson

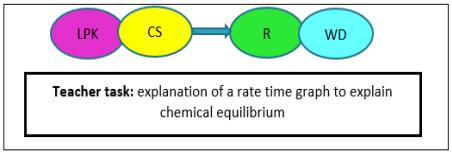
Episode Extract	Overview/Qualitative in-depth analysis
<u>Checking for learner prior knowledge on chemical equilibrium:</u> 0-4mins **Sara:** …So I need to get a sense of what you guys know and what you guys do not know. So, when I say chemical equilibrium, what comes into mind? Can I just take a couple of hands? By show of hands, when I speak of chemical equilibrium, what am I talking about? Yes, sir? **One std:** The number of reactants and products are equal **Sara:** The number of products and reactants are equal...we retain that one, Ok? Ah guys, hands up...I want to see what you guys know so that I can rectify and then we can teach each other about chemical equilibrium? **Another std:** ratio of reactants and products **Sara:** Ok, what is that; the ratio of products to reactants? What do we use to represent them? What is the term that I can use to...? **One std:** Equilibrium constant **Sara:** Yes, equilibrium constant which is the ratio of products to reactants. Is there something else that comes to mind when we speak of, when we speak about chemical equilibrium? **Another std:** a time whereby during the reaction, reactants and products remain constant **Sara:** So, she said that um, equilibrium is established when products and reactants remain constant. Is that what you said? Stds: Yes ma'am **Sara:** Yes. I want to hear something...something **Another std:** That point when the rates of the forward and reverse reactions are equal **Sara:** Yes...the rates of the forward and reverse reactions are equal...ok girl...chemical equilibrium is not just about one thing. Do we all agree on that? **Stds**: yes, ma'am **Sara:** You do not just have to say that the rates are equal; there is something else that you must have heard about chemical equilibrium. I am not asking about the definition of chemical equilibrium. I want to know about what you know about chemical equilibrium as a whole, under the umbrella, chemical equilibrium. **One std:** It is when the conditions are at optimum, they are at most optimum temperature, pressure, concentration...	**<u>Overview:</u>** In this teaching segment, Sara is probing for learners' understanding of what entails chemical equilibrium, to get an overview of what learners know about the concept. **<u>Qualitative in-depth analysis:</u>** There is no episode as the task involves only the learner prior knowledge.
<u>Laying out the lesson structure and sequencing:</u> 4-10mins ***Episode 1*** **Sara:** So, what I will be covering today under the umbrella of chemical equilibrium is the nature of chemical equilibrium (puts in a slide on nature of chemical equilibrium). When I speak about the nature, I am saying that chemical equilibrium is a dynamic process. I am saying that chemical equilibrium involves aqueous solutions as well as gases. I am saying that under chemical equilibrium, the rate of forward reaction is equal to the rate of the reverse reaction. Specific word there is equal rates, equal rates. And then I will be moving on to conditions required for chemical equilibrium to be established. Under that I will be covering concepts of the fact that chemical equilibrium occurs in a closed system, chemical equilibrium involves reversible reactions and the fact that when chemical equilibrium is established, the concentrations become constant. Not equal, but constant. That is the keyword. And thereafter I will be covering the factors that are affecting chemical equilibrium. We will have finished defining chemical equilibrium, eh, what chemical equilibrium is. Then we move over to what affects chemical equilibrium, mainly concentrations, which is, which involves gases as well as um, aqueous solutions. We will	**<u>Overview:</u>** In this segment, Sara provides students with an overview of the concepts that will be discussed in a sequence in which they will be presented in the lesson. **<u>Qualitative in-depth analysis:</u>** By providing learners with the lesson objectives and the sequence in which the concepts will be discussed, an aspect of curriculum saliency takes form as learners get to understand the importance of the lesson (CS). In the act of giving the sequence of the lesson; under an aspect of factors that affect chemical equilibrium, Sara mentioned a catalyst with the purpose of checking students' understanding of the effect of a catalyst on a chemical reaction. This is an aspect related to learner prior knowledge (LPK) as students were able to give the function of a catalyst.

be covering the effects of pressure, which mainly deals with gases and the effect of temperature. Just a quick question, I know we will cover it as we go along with class. But a catalyst; we all know what a catalyst is from physics. We are physicists, we are scientists. So, we know what a catalyst is. Does the catalyst affect the equilibrium position? **Stds:** No **Sara:** Why? What does it do? **One std:** It creates an alternative route in which the reaction can proceed **Sara:** In which the reaction can proceed. It maybe speeds up the reaction. So, it's not the part of the factors that affect it. Its main purpose is to speed up the reaction. So, when I did this...by the way, I will relate all these three factors that we have mentioned and explained how they shift the equilibrium governed by the Mr. Le Châtelier's. So, relate those three factors that affect chemical equilibrium to Le Chatelier's principle. And if time permits, I would love to cover the various ratios that you guys can calculate after, when or after, or before equilibrium has been established. Mainly what I am talking about is the reaction quotients. Reaction quotients mainly deal with what happens before chemical equilibrium is established, as well as after. Not during, but before or after. That is calculating the quotients. So that is the reaction quotient. And then when we deal with the equilibrium constant, the equilibrium constant is the ratios of products and reactants when equilibrium is established. So that is at equilibrium. When we calculate the equilibrium constant, we are doing it at equilibrium. And eh, interpreting the Kc value. The value that I get for Kc, what it means. Ok, so that is basically what we will be covering during this one-hour session, or I mean the two-hour session. Ah, there will be a break please. A two-hour session, one hour I will cover the nature of chemical equilibrium as well as the conditions required for it to be established. And then in the second session I will cover the factors affecting chemical equilibrium and eh, the last part I do not think we will be able to cover because I do not want to cover something that we won't finish. That is very calculation intensive, so if we start, I don't think we will finish in time.	Two components are interactively used in this episode as displayed in the TSPCK map below. **An interwoven basic TSPCK episode: CS/LPK** 
<u>A review on irreversible/reactions that go to completion:</u> 10-13mins ***Episode 2*** **Sara:** So, chemical equilibrium; before we get started on defining what chemical equilibrium is, I am sure that before you guys got started on this topic, you guys maybe dealt with reactions that went to completion (presents a slide displaying two chemical reactions.) When I speak about reactions that go to completion, I mean reactions that have a single arrow. That is what you guys may be dealt with.  So, when a reaction is written, when a chemical reaction is written, as...eh the first one, what does the first one represent? So, as I was asking, the first reaction that I see, what kind of a reaction does it represent? **One std:** A reaction that goes to completion **Sara:** And what happens? When it goes to completion, what do I mean when I say a reaction goes to completion? **Same std:** It reacts and forms other substance **Sara:** Products, yes... **Another std:** It went from one form of something to another... **Sara:** Ok, so what I wanted, eh the essence of what I wanted is that reactants react to form products. That is all that happens. All that CH4 and Oxygen will react to form carbon dioxide as well as the water (Referring to the first equation on the slide). You guys have done organic chemistry, right? What kind of a reaction is that, under organic chemistry? **Stds:** Combustion	**<u>Overview:</u>** As a review on what learners know about reactions, Sara discusses a concept on reactions that go to completion, in which all reactants get used up in forming products. **<u>Qualitative in-depth analysis:</u>** Sara introduces the topic by drawing on learner prior concepts (LPK) around reactions that go to completion. Talking about reactions that go to completion at this point could be a sign that Sara is aware of one common misconception by the learners that all reactions go to completion. A chemical reaction (burning of methane-CH_4) is given as an example of a reaction that goes to completion, which is represented with a single headed arrow on the slide (R). Emphasis is made on why this reaction goes to completion, where all reactants react to form products. This is evidence of curriculum saliency (CS), an important concept that students should understand at this point which will be used to introduce reactions that do not go to completion (reversible reactions). The emphasis is done using a concentration time graph that shows a gradual decrease in the concentrations of reactants, until all reactants are used up. A graph is another form of representation (R).

Sara: Exactly. It is an example of a combustion reaction. So, this particular reaction that I spoke about as I was saying that all reactants react to for products. Which means that after all this CH4 which is what? What is CH4? **Stds:** Methane **Sara:** Methane. After all this methane has reacted with oxygen and produced carbon dioxide as well as water, after the reaction has gone to completion, we will have no CH4, and we will have no oxygen in the system. So that is what I wanted to get across...So in this first graph that I have represented here, I have drawn concentration against time (referring to the graph on the slide). And as you can see, basically what this line represents is the combustion of CH4 to Carbon dioxide. Initially we have a lot of reactants. This line represents CH4 and oxygen together. So, as you can see initially, we have some sort of concentration of CH4 and O2, and as the reaction proceeds, proceeds, proceeds, we have a decrease in the number of, eh in the concentration of reactants, as these reactants form products, right.	In this teaching segment, Sara used three TSPCK components together in an interwoven sequence as displayed in the TSPCK Map below with one component distinguishably repeating. **A sophisticated TSPCK episode: LPK/R/CS/R** 
Introducing reversible reactions: 13-18mins ***Episode 3*** **Sara:** So, when we deal with this particular topic that we are covering, chemical equilibrium, we deal with reversible reactions**.** So, from what you have learnt from what you know, how will I see that this reaction is reversible or not? How will I identify that this reaction is reversible? **One std:** When one arrow faces the reactants, and another faces the products... **Sara:** Ok, so she said that we see that this reaction represents a reaction that is in equilibrium by the double arrow. Right, the arrows point towards the product side, and they point towards the reactant side. Well, that is true. So that is the answer I was looking for. So, this double arrow shows us that this reaction; 1. is reversible, and 2. That it is in equilibrium by the way. So just add that...So in the circle that I pointed to there (on a reversible reaction), the double arrow represents that em, this reaction is 1. Reversible and 2. That it is in equilibrium. We all agree right? **Sara:** So, when I look at this, have you guys heard of the Haber process? Is this the Haber process? **Stds:** Yes **Sara:** Yes. What is the product that forms? **Stds:** Ammonia **Sara:** Yes, so it represents the Haber process that you guys were talking about. So, nitrogen reacts with hydrogen to form ammonia. We have established that this is a reversible reaction and that it is at equilibrium neh? So, we can break down the two reactions that we have to show what and what is reacting, and what and what is reacting. And the forward reaction we are seeing the nitrogen reacts with the hydrogen to form ammonia. But at the same time, um, ammonia is reacting itself, breaking down to form nitrogen and hydrogen. So, another thing that we should note about reversible reactions or reactions that are in equilibrium is that these reactions do not go to completion. They do not go to completion, unlike our unidirectional reactions neh? So, reactions in equilibrium do not go to completion. They continuously occur. So as the forward reaction is happening, the backward reaction is also taking place. I have noted there, the forward reaction is nitrogen and hydrogen going to NH3, and eh, NH3 converting back to nitrogen and hydrogen. So, I have also noted that these two reactions occur simultaneously. What is simultaneous? **Stds:** Same time **Sara:** The same time. Thank you. They occur at the same time. So, these reactions occur, as one is forming, the other is breaking down. I also noted that reactants react to form products and at the same time products react to form reactants. **One std:** Same time, it is dynamic	**Overview:** Sara explains further that both forward and reverse reactions occur simultaneously, which means that they both take place at the same time; hence the reaction never really stops. She then noted that because of the simultaneous nature of the reactions, chemical equilibrium is referred to as a dynamic process. **Qualitative in-depth analysis:** Noting an important condition for chemical equilibrium to be achieved "reversible reactions"; which are reactions that do not go to completion is evidence of curriculum saliency (CS). Sara draws on learners' understanding of features of reversible reactions (LPK). She affirms the response from the learner that reversible reactions are represented by a double headed arrow (R). She further explains the reversible nature of reactions by referring students to a chemical reaction on formation of ammonia in a Haber process. The emphasis details that reversible reactions do not go to completion, but continuously occur. This is evidence of learner prior knowledge (LPK) which comes in the form of a learner misconception in which learners think that a reverse reaction can only begin when all reactants have been used up. A possible reason for this misconception could be that students got accustomed to one directional reaction that go to completion which are introduced to them in earlier grades. Further emphasis shows that the two reactions occur simultaneously hence the dynamic nature of chemical equilibrium; a concept that is difficult for students to comprehend (WD). The episode has a repeating LPK component. The component first came through as a pre-concept requesting learners' understanding of reversible reactions, and later as a common learner misconception. The episode displays both linear and interwoven sequences. The episode portrays an interactive use of four overlapping TSPCK components in an explanation given by Sara as displayed in the TSPCK map.

Sara: "Occurs at the same time, thank you. So, these reactions occur, as one is forming, the other is breaking down. So, we call that a dynamic process, simultaneously occurring".	**A sophisticated TSPCK episode: CS/LPK/R/LPK/WD** 
Describing a condition for reversibility- a closed system: 18-19mins ***Episode 4*** **Sara:** "And then the last point that I pointed there is that a reversible reaction can only take place in a closed system. And then now, that's another word that I have come up with, a closed system. What is a closed system?" **One std:** It is a system whereby the contents of a reaction are not allowed to react with the surroundings. **Sara:** True. There is nothing that I put in and there is nothing that comes in. So basically, that is what eh, some of the elements that go into explaining what chemical equilibrium is...	**Overview**: Sara endorses on the learner response about what closed systems are without any expansion to the explanation given. **Qualitative in-depth analysis:** A condition necessary for reversibility of reactions "a closed system" is explained; an evidence of curriculum saliency (CS), drawing on learners' own understanding of the concept (LPK). Two components of TSPCK are interactively used in this teaching segment in an interwoven sequence as displayed on the TSPCK map below. **A basic TSPCK episode: CS/LPK** 
Describing an equilibrium state using a concentration time graph: 19-22mins ***Episode 5***  **Sara** "Ok let me just show you this". You see in this little diagram that I have represented here, I am showing concentration against time of this reaction neh. You can see that initially, I have high concentration of hydrogen and a high concentration of nitrogen (referring to the graph on the slide), and I have nothing of NH3. This means that at the beginning of the reaction, we only have the hydrogen and nitrogen. As the reaction occurs you see the gradual decrease of the hydrogen and nitrogen and a gradual increase of NH3. Why is that? **One std:** So, at the beginning there are no products. So as the reaction begins, the products start forming. **Sara:** Yeah. So, the reactants are reacting to form products. That is basically what this graph shows us. And as we can see, at a certain time, this suddenly has stopped, well in terms of concentrations over time. So why is it, you know there is a point where the concentration of hydrogen, nitrogen and ammonia are no longer changing. Why is that? **One std:** They have reached the equilibrium... **Sara:** "They have reached an equilibrium position. But does equilibrium mean that there is no reaction taking place? No, because we stated that equilibrium is what process?" **Stds:** dynamic...constant... It is a dynamic process **Sara:** Yes, it's a dynamic process. It is a dynamic process. So, reactions are continuously occurring. It is just that you cannot see a change, but there is something occurring neh	**Overview:** Provides a detailed description of change in concentrations of reactants and products in a concentration time graph. She further pointed out that at some point; the concentrations of reactants and products do not change (the circled parts on the graph referred to on the slide) but remain constant which does not necessarily imply that the reaction has stopped. **Qualitative in-depth analysis** Sara explains a state of equilibrium using a concentration versus time graph for a reaction on the Haber process discussed earlier in the lesson. A graph acts as a representation (R) which she uses to explain the changes in concentrations across the graph. Sara then asked learners why the concentrations of reactants decrease whilst that of a product increases, which they correctly respond to and she affirms the response by the learner and then points students to a position on the graph where concentrations of reagents (products and reactants) are not changing and explains that just because the concentrations of reactants and products are no longer changing but remain constant does not necessarily mean it has stopped. This is a common learner misconception, which then brings forth another component of learner prior knowledge (LPK). She continues to show that the reactions are continuously happening and that this is a dynamic process; a concept difficult to understand (WD). The difficulty of this the dynamic nature of chemical equilibrium is seen in Sara's statement where she argues that the reactions are

	continuously happening, even though one cannon visually see the change. Three different TSPCK components are interactively used by Sara in this teaching segment. The components are pictorially presented in a TSPCK may below. **An interwoven proficient TSPCK episode: R/LPK/WD** 
<u>Explaining the dynamic nature of chemical equilibrium:</u> 22-26mins ***Episode 6*** **Sara:** Let me explain why you cannot see anything. So, when we talk about chemical equilibrium, I said that you cannot see what is taking place neh. This is because at a macroscopic...here is another terminology; what is macroscopic? **Stds:** you can only see with a microscope? **Stds:** We cannot see with our own eyes **Sara:** Microscopic, we cannot see with our naked eyes... So, as I was trying to explain, when chemical equilibrium is established, sometimes it can still be that you cannot see what is happening, or it appears as if there is nothing happening within this reaction. It seems like the reaction has gone to completion. But, at a microscopic level, there is something that is taking place. Typical example will be this (referring to a closed bottle with water). This is what system? **Stds:** Closed **Sara:** It is a closed system. So, matter and what? **Stds:** energy **Sara:** Cannot... **Stds:** leave or enter the system **Sara:** Leave or enter the system (at the same time as the students). Say this water is in chemical equilibrium, how can you see that it is ok, how can you explain that it is chemical equilibrium? **One std:** No reaction is occurring... **Sara:** It is in chemical equilibrium? **Another std**: There is no reaction happening... (misconception) **Sara:** There is a reaction occurring. That is what I wanted to get at. **Stds:** Oooh... **Sara:** At a macroscopic level, it seems as if there is nothing happening like we said. But if we were to look deeper, if we had eyes that could see at the macroscopic level, there would be a reaction taking place... So, when we are dealing with water…So, I said H2O changes from liquid to gas. I can see this at a macroscopic level, at a microscopic level, I am sorry. At a microscopic level. How do I see this? This bottle of mine has water in liquid form. But you can see at the top, there is like fuzzy things that you can see. So, water evaporates. It goes up. And then when it evaporates, what form does it change to? The phase? **Stds:** gas **Sara:** It goes to a gaseous phase. And then it does return, it does…. you can see here, there are some droplets that we can see. These represent what, condensation. So, there is evaporation that is taking place as the water goes up into the gaseous phase. And then there is a time, as this reaction is taking place...so I put this water in the morning, it was just liquid. Ok it was just liquid at the bottom. As time went by...evaporation occurred, but not all of it evaporates neh. So there comes a point in time whereby there is a lot of gaseous phase water in the system. The gaseous water particles then collide to form liquid phase. It goes from the gases phase to the liquid phase, back to the liquid phase. It changes phase and	**<u>Overview:</u>** Sara explains the dynamic nature of chemical equilibrium using a bottle containing water to demonstrate the simultaneous change of phase. **<u>Qualitative in-depth analysis:</u>** To explain the dynamic nature of chemical equilibrium; a difficult concept for students (WD), Sara pointed out that although at a macroscopic level it may appear as if the reaction has stopped, the reaction is actually still happening. She refers students to a bottle of water which she uses to explain how both evaporation and condensation continuously happen in a bottle. This is an example of a macroscopic representation (R). Through question an answer, Sara points out to the students that the bottle is closed and hence cannot allow matter in or out of the system. This could be her way of emphasizing on a condition that will allow for reversibility to occur, and hence chemical dynamic equilibrium. As the discussion progresses, some learners express a misconception by indicating that there is no reaction at equilibrium, which is another form of learner prior knowledge (LPK). Sara indicates that there is still a reaction happening, and argued further to eradicate this misconception, by explaining to students how water in a bottle changed phase through evaporation and condensation that happen at the same time within the system (CS). This teaching segment displays an interaction between four components of TSPCK as displayed in a TSPCK map below. **A Sophisticated TSPCK episode displaying interwoven components: WD/R/LPK/CS** 

the liquid that is in there, some of it again evaporates and form water in the gaseous phase...so it continues to occur. This is a classic example of phase change that is in equilibrium. So, it is a phase change because we are changing from... **Stds:** Liquid to gas... **Sara:** And gas... **Stds:** To liquid... **Sara:** But it is also a phase change because we have liquid going to gases phase. That is what I wanted to get at. So, at dynamic equilibrium, the forward and reverse reactions are continuously occurring at the same rate.	
<u>Introducing the rate time graph:</u> 26-31mins ***Episode 7***  **Sara:** So, there is a graph that I drew from reaction rate vs time. What is rate? **One std:** It is the duration...yeah it is the duration... **Sara:** "Rate not time. A rate is the speed. It is a speed, speed". So, I drew a graph of rate against time. Eh initially, as I said before, the water initially starts off as a liquid. So, there is eh, the rate at which liquid water changes into a gas starts off as high. But with the water initially at a gaseous phase, initially the rate is zero, Why? **Stds:** There was no gas in the container **Sara:** There was no gas in the system that we are looking at. So as time went on, in the closed system by the way, as time went by, this liquid form of water, the particles of H_2O finally got enough energy to escape the liquid form and they now go into the gaseous form. So, as you can see at the beginning, initially there is liquid water, and there is no gas, because there is no gas initially. As we go on, as time elapses, the liquid water starts forming gas, so there were gaseous molecules of water being formed, formed, and formed. So, the rate at which liquid water evaporates decreases with time and the rate at which gaseous water condenses back into liquid increases for some time. There is a certain point in time again, when we are dealing with chemical equilibrium, it is time specific. There is a time, this time when chemical equilibrium is established. As you can see there...can I get one person to show me where chemical equilibrium was established in that graph? Go to the board...can you show me where it is established? **One std:** (points onto the graph) **Sara:** Why do you say that? **Same std:** Because we have the same eh, constant liquid and gas **Sara:** What is constant? **Same std:** Eh, the H2O here and here are constant (pointing at liquid and gaseous states respectively). **Sara:** Ok tell me, at this part we say chemical equilibrium is achieved. What do we mean by that? **Stds:** Rates are equal **Sara:** Yes...the rates become equal. That is where they what, they meet. So, the rates become equal when chemical equilibrium has been established, neh. Does this mean no reaction is taking place? **Stds:** no **Sara:** It is still occurring right. It is just that what is equal? **Stds:** The rate **Sara**: What about concentration? **One std**: constant **Sara:** They are constant; there is no change in concentrations. Constant means no change.	**<u>Overview:</u>** Sara introduces students to a rate versus time graph used to describe or represent a reaction at chemical equilibrium. **<u>Qualitative in-depth analysis:</u>** The teacher introduces a rate versus time graph to explain chemical equilibrium by drawing on learners' understanding of rate (LPK). The response given by the student is however incorrect as they referred to rate as time. Sara commented on the learner's response and indicated that rather rate represents speed and not time, as implied by one of the learners. Explaining what rate is, is an important aspect towards understanding rates of reactions at chemical equilibrium, an aspect of curriculum saliency (CS). The graph displaying the change of phase of water is presented and described. The graph is a form of representation (R). Emphasis is made on a point on the graph where the rates of forward and reverse reactions are equal which is when the reaction has reached equilibrium. This is a difficult concept for students since they cannot visualize how the two reactions can happen at the same time (WD). A possible reason for this difficulty being, they got introduced to reactions that go to completion before this concept which is also highlighted in the question that Sara asked. Further emphasis on equal rates and constant concentrations is used with reference to the rate graph of water. Four TSPCK components are interactively used in this teaching segment that introduced learners to a rate time graph. The components are displayed in a TSPCK map below. **A linear Sophisticated TSPCK episode: R/CS/R/WD** 
<u>Emphasis on characteristics of chemical equilibrium:</u> 31-40mins ***Episode 8***	**<u>Overview:</u>** The segment begins with a doubt from the learner with regard to rates of reactions at chemical equilibrium.

One std: Ma'am, so the rates of reactions are equal? The reactants are forming products and the products are forming reactants?
Sara: Yes, and the products themselves are reacting to form eh, the reactants. That is why I said it occurs simultaneously. Remember when we showed the two graphs there, not the two graphs, I am sorry. The two equations there on the Haber process. I did say these two reactions occur simultaneously. When I say they occur simultaneously, I mean they are occurring at the same time. We can do a final exercise. I need three; four...come in the front, quickly, quickly, quickly...
Stds: Run to the front
Sara: So, the guys stand here...so the guys represent water in liquid form, neh? The girls represent water in its gaseous form. These are the reactants (boys), and these are the products (girls). It can be either way. It does not matter right. So, what can we notice about this, concentration wise?
Stds: There is more of these (boys-liquid water).
Sara: there is more of these. So, does that mean the system is not at equilibrium?
Stds: no
Sara: It does not mean the system is not at equilibrium. So, at equilibrium, it does not mean that the concentrations are equal. That is what I wanted to show. There is more of the guys. There is a high concentration of the guys than the girls. So, concentrations do not need to be equal for...



One std: For chemical equilibrium.
Sara: But I want to show what is equal neh. So, as he moves towards this side, you move towards this side, at the same time...move, move, move...next, next, next...So we are still at equilibrium, move, move, move...everyone move (students move at the same time. What I want to show here is what, characteristics of equilibrium.
One std: Concentration...
Sara: no there is something about equilibrium. The fact that they are moving. What are they doing?
One std: The rates are the same
Sara: Yes, and I also wanted to get to the dynamic nature of equilibrium. So, as they are moving, everyone is moving. But when I look at it, it seems as if the system is not doing anything. But they are constantly moving. It is just that the concentrations remain the constant and it is as if nothing is happening. But they are still moving. Everyone is moving.
One std: So, the concentrations do not have to be the same
Sara: (at the same time) concentrations do not have to be the same, equal, equal...
Same std: for equilibrium to be established
Sara: There is four, there is three. I said that my system is in equilibrium. When you guys started moving, there was always three this side, and there was always four this side. So, the concentrations are not equal. But what is happening is that the rates are equal. I have always seen four there. I have always seen three there, four there, three there, four there, three there...That's what I wanted you to get. Concentrations are not equal. They are what?
Stds: Constant
Sara: Constant yeah. Thank you. And the rates are what:
Stds: equal
Sara: When they are moving around what are they showing me?
Stds: That the nature of equilibrium is dynamic
Sara: Is dynamic. So, equilibrium constantly occurs. At equilibrium, the reactions are still happening, still happening, still happening. It is just that when you look at it at what level?
Stds: Macro, micro...macro...

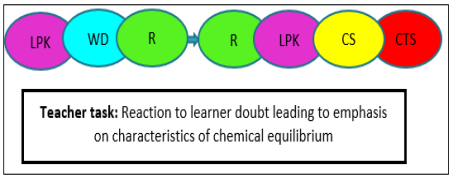
Sara used this opportunity to emphasize on characteristics of reactions that are at chemical equilibrium.

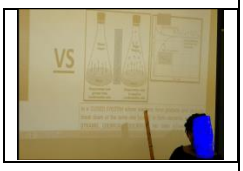
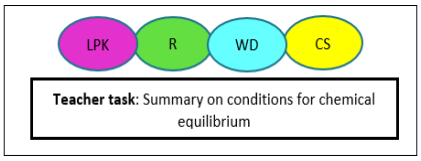
Qualitative in-depth analysis:

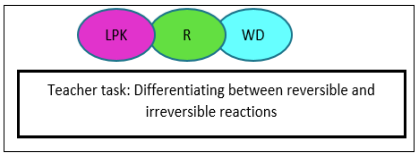
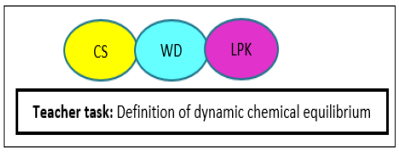
The explanation is initiated by a learner doubt on rates of reaction at an equilibrium position. This is a component of learner prior knowledge (LPK) which might have caused confusion for the learner. On explaining this, the teacher refers the learner to the two chemical reactions presented earlier in the lesson on formation of ammonia gas, which also reverse forming its constituent reactants: hydrogen and nitrogen gases (R). A demonstration with a group of learners follows, which is another form of representation at a macroscopic level (R), to show that the two reactions continue to happen simultaneously at equal rates, although the constant nature of the concentrations of reagents may cause one to think that there are no reactions happening. This is an aspect considered difficult for learners (WD). Sara then emphasized that the concentrations of reactants and products do not necessarily have to be the same, by referring students to the ratio of boys to girls which she used to demonstrate a reaction that is in equilibrium. This statement is made to address a common learner misconception with regard to concentrations being equal, hence a learner prior knowledge (LPK). Sara continues by giving a detailed emphasis on characteristics of a reaction at an equilibrium displaying further its dynamic nature (CS). This segment ends a question an answer strategy that confirms learners' understanding of the concept (CTS).

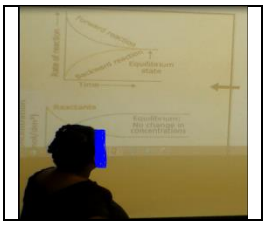
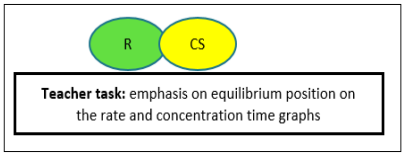
The episode shows an interaction between five TSPCK components with two other components evidently repeating. The components are pictorially presented in a TSPCK map below.

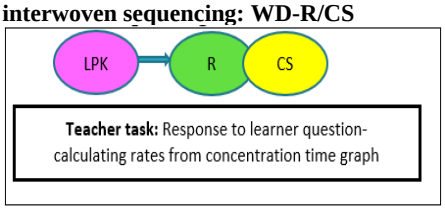
A Sophisticated TSPCK episode displaying linear and interwoven features: LPK/WD/R-R/LPK/CS/CTS

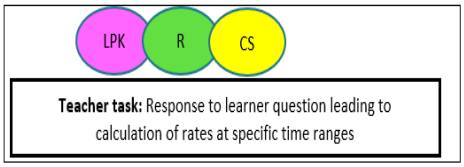


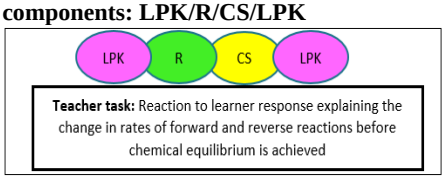
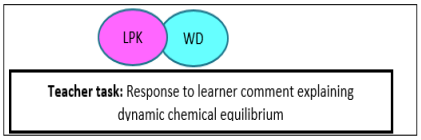
Sara: Macro...you know; the pronunciation doesn't matter. Don't worry about the pronunciation, macro. All I care about is you being able to write it correctly. So, when you look at what level? **Stds:** macro **Sara:** It seems as if nothing is happening. But if we go deep enough, at what level? **Stds:** micro **Sara:** At microscopic level, you can see that it is dynamic. The concentrations are constant. The rate is... **Stds:** Is equal... **Sara:** Thank you very much... Giving a round of applause to the group that did the demonstration **Stds:** Applause	
<u>Summary on conditions necessary for equilibrium:</u> 40-43mins ***Episode 9*** **Sara:** Ok so what is needed for equilibrium to occur? **One std:** It should be in a closed system **Sara:** There is no what and what that is leaving this system? **Stds:** Matter and energy **Sara:** "Right. So, this basically, what is happening in this flask (displays a slide with two flasks), it shows that initially, what we are getting at is that the evaporation rate initially is high because we initially had water right. And then all this water wants to, it has a lot of energy and it wants to go upwards neh, to form the gases form. So initially, there is a high reaction rate of these molecules (liquid water) because there is nothing initially, right? So, there is a lot of water vapor forming initially because there was nothing. But it gets to a certain point where there is a lot of water vapor, and then they should be up there. Then they decide that no guys, we need to move down. So, condensation takes place, and then the water changes its phase from gases to liquid, neh. Do we all agree there?  **Stds:** Yes **Sara:** Is there anything that someone does not understand in what I have said? **Stds:** No **Sara:** Ok. So, I also said that there is a closed system where reactions form products and products break down, um at the same rate or speed to form reactants, we can say a dynamic equilibrium has been achieved or reached, provided...there is another condition...provided the temperature and the pressure, the concentration itself at equilibrium does not change. Those are the three, we will also deal with them later. These should be ringing bells about something that is to come. The concentration, the pressure and temperature... they should all be constant. Do we all agree? **Stds:** Yes **Sara:** So, we said that dynamic equilibrium has been achieved. The reason why I called it dynamic equilibrium is to show you some intelligence by the way. When you say dynamic equilibrium, we are showing now that this reaction is continuously taking place although it may look as if there is nothing happening. That is why I called it dynamic chemical equilibrium...	**<u>Overview:</u>** This teaching segment involves an emphasis on conditions for chemical equilibrium, using a flask containing water to explain how it reaches chemical equilibrium through evaporation and condensation processes. **<u>Qualitative in-depth analysis:</u>** Sara starts this episode by reviewing on the conditions necessary for chemical equilibrium which were discussed earlier in the lesson. This is knowledge that learners should now have in place which has then become their knowledge (LPK). The emphasis is done through use of closed flasks as microscopic representations (R). Further emphasis is made on the simultaneous nature of reactions at an equilibrium state; hence the process is dynamic; a concept difficult to understand (WD). Sara also highlighted that for a reaction to remain at equilibrium; conditions such as temperature, pressure and concentration should not change but remain constant. This emphasis is an aspect of what is important; an evidence of curriculum saliency (CS). This episode shows an interaction between four TSPCK components as displayed in a TSPCK map below. **An interwoven Sophisticated TSPCK episode: LPK/R/WD/CS** 
<u>Differentiating between reversible and irreversible reactions:</u> 43-44mins ***Episode 10*** **One std:** What do we call a reaction that goes to completion? **Sara:** A reaction that? **Same std:** That goes to completion? **Other stds:** (in a chorus) irreversible	**<u>Overview:</u>** The segment is initiate by the learners' questions on reverse versus irreversible reactions **<u>Qualitative in-depth analysis</u>** The discussion is prompted by students' questions on reactions that go to completion versus those that do not

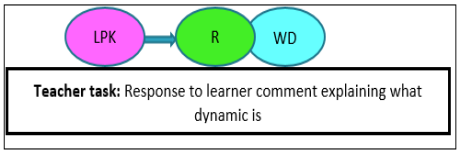
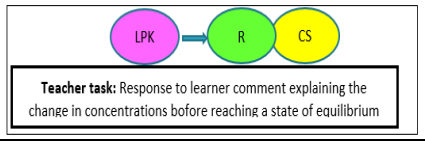
Sara: Yeah, irreversible reaction. You can just put non- or irreversible…Irreversible and it goes to completion. It is the same thing. **Another std:** Why do you say a reversible reaction does not go to completion? **Sara:** Because chemical equilibrium is… not all reactants are used up. We still have both products and reactants at equilibrium. As you can see with the demonstration that I showed you with your friends here, there was four, and there was three here. That is equilibrium, so that means that we still have reactants, and we still have products at equilibrium. And they start moving at the same rate, they start moving. The forward and reverse reactions are happening simultaneously, and it is a continuous process that never ends. This is a dynamic process remember. So that does not mean anything is used up.	go to completion, prompted by a common learner misconception which is learner prior knowledge (LPK). Sara explains this by showing that reversible reactions do not go to completion because the reactions occur simultaneously, hence there will always be reactants and products within the system. This is a component considered difficult for students (WD). The explanation given draws students attention to the demonstrations with a group of students earlier in the lesson; a microscopic representation (R). The episode displays an interaction between three TSPCK components as presented in the TSPCK map below. **An interwoven Proficient TSPCK episode: LPK/R/WD** 
<u>A definition of chemical equilibrium</u>: 44-46mins ***Episode 11*** **Sara:** So, I came up with a definition for dynamic chemical equilibrium. There are certain words that must be in the definition. That is why I want you to get that. So, I said the dynamic equilibrium is the state that takes place in a closed system where the forward and reverse reactions take place at the same rate. The concentrations of reactants and products remain constant. Does that not cover everything that we have talked about? **Stds:** It does **Sara:** Yes, it does. What I wanted in the definition is the fact that it is a state. What do you guys understand when I talk about a state? What is a state? **One std:** It is a phase... **Sara:** Not really a phase...a phase is like an instant in time. It is like, from here, this is what happens. From this time, a state is like from this time on tell the parents that you will pass until forever. From this point, I will study physics to the best of my ability. So, it is an instant in time, where you say from now on...it's like a state that happens at a certain time. So, it is a state takes place in a closed system. "Closed system" is important, where the forward and reverse reactions take place at the same rate. Then I moved forward that the concentrations of reactants and products remain constant, not equal. Do not mix constant and equal, and rate and concentrations. Concentrations remain what? **Stds:** constant... **Sara:** And rates? **Stds:** Equal... **Sara:** Thank you very much...ok I said something about at equilibrium, three things must not change. What are those? **Stds:** Temperature, pressure and concentrations... **Sara:** Yes, temperature, pressure and concentration remain what? **Stds:** Constant **Sara:** What I wanted in the definition is the fact that it is a state. What do you guys understand when I talk about a state? What is a state? **One std:** It's a phase... **Sara:** Not really a phase...a phase is like an instant in time. It's like, from here, this is what happens. From this time, a state is like from this time on	**<u>Overview:</u>** This is a segment in which a definition of a chemical dynamic equilibrium is given and puts more emphasis on the constant nature of the concentrations whilst rates are equal. **<u>Qualitative in-depth analysis:</u>** Sara provides a definition of a dynamic chemical equilibrium. The definition includes important conditions, which are aspects of curriculum saliency (CS), nature of rates of forward and reverse reactions, which is a difficult aspect (WD) and finally the constant nature of concentrations of reagents; a common learner misconception which is learner prior knowledge (LPK). The explanation given shows an interaction between three components of TSPCK as displayed on the TSPCK map below. **An interwoven Proficient TSPCK episode: CS/WD/LPK** 

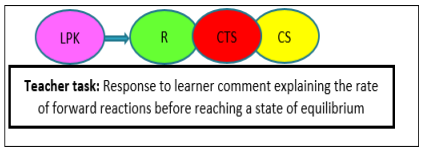
tell the parents that you will pass until forever. From this point, I will study physics to the best of my ability. So, it is an instant in time, where you say from now on...it's like a state that happens at a certain time. So, it's a state takes place in a closed system. "Closed system" is important, where the forward and reverse reactions take place at the same rate. Then I moved forward that the concentrations of reactants and products remain constant, not equal. Do not mix constant and equal, and rate and concentrations. Concentrations remain what? **Stds:** constant... **Sara:** And rates? **Stds:** Equal... **Sara:** Thank you very much...ok I said something about at equilibrium, three things must not change. What are those? **Stds:** Temperature, pressure and concentrations... **Sara:** Yes, temperature, pressure and concentration remain what? **Stds:** Constant	
<u>Emphasis made on an equilibrium position on the rate and concentration time graphs:</u> 46-48mins ***Episode 12*** **Sara:** So, we have spoken of this graph neh? Rates against time. And that is the one that shows that at equilibrium... **Stds:** the rates of reactions are equal... **Sara:** So, when you draw such graphs, you should know what it means. You know, the graph is there, but what does it mean? So, what you must do is that when you draw such graphs especially in the exam, you have got to draw maybe a vertical line (referring to a vertical line from a point where reactions have reached equilibrium), and maybe shade rest of this area (equilibrium position), and then write that, this is equilibrium. So, you must put just a bit of a vertical line here, and shade this region, and write like the equilibrium state, or chemical equilibrium, something along those lines neh? And then with the second one (concentration against time), you should also draw a line where concentrations are.  **One std:** Are constant **Sara:** Constant...so when I draw like a vertical line here...make it a habit to draw that vertical line and shade this section and show them that chemical equilibrium has been achieved.	**<u>Overview:</u>** Highlighting the important positions on the rate and concentration time graphs that represent chemical equilibrium. **<u>Qualitative in-depth analysis:</u>** The teacher emphasizes on the rate and concentration versus time graphs that students should know which sections/areas within the graphs represent an equilibrium state. Graphs act as representations (R). An emphasis is made on what is important about the graphs, indicative of aspects of curriculum saliency (CS). The episode has two TSPCK components interacting as displayed in the TSPCK map below. **An interwoven Basic TSPCK episode: R/CS** 
<u>Calculating rate from concentration time graph:</u> 48-55mins ***Episode 13*** **One std:** So, ma'am, you said like, it's concentration, and then it's time. When you take concentration of maybe 4.3 over 2 maybe... **Sara:** Oh, concentration over time? **Same std:** Yes, if you put that on a calculator, what are you calculating? **Sara:** Ok, concentration over time, what is that? Do your fellow classmates know? **One std:** Concentration over time? **Sara:** Yes, what is that? **Same std:** It's the rate... **Sara:** Yes, that is the rate. So, we take this graph (pointing at the concentration time graph) and then you convert it to the other one (the rate time graph); you know, we make the other one. That's how the other graph came about. So, when you calculate, so let us just do it...it is fun because this one has values. So, we say that equilibrium is achieved at time what? **Stds:** at 2...at 2 point something...	**<u>Overview:</u>** When one student asked what is being calculated from dividing concentration with time, Sara took that as an opportunity to see if the rest of the class can relate that to anything that they have learned before. A concept of rates of chemical reactions is discussed in the earlier grades when students are first introduced to chemical reactions. So, this is a pre-concept needed towards the understanding of the current topic, chemical equilibrium. Sara then uses this moment to help students understand how rate is calculated. She does this by asking students to calculate the rate at which reactants form products and vice versa at specified time ranges. Sara, however, did not specify to the students that obtaining zero when doing calculations for rates using this formula does not necessarily mean that the rates are both zero which

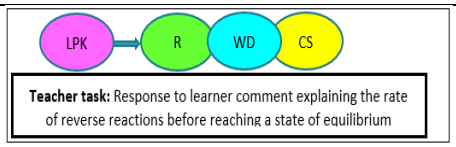
Sara: At 2, no... Yeah 2 point something, because you see at 2, there is still something happening (showing the steepness of the graphs) to this green one. So, let us say 3. We are sure that chemical equilibrium has been achieved at 3. Can you calculate then, the rate of nitrogen, the rate of hydrogen and the rate of ammonia? Let us just, give me a numerical value of each of those...eh H_2 is 5, N_2 is 3 and then NH_3 it is a 2... Can you also calculate the rates of all at time 5? First you did for time 3, right? So now let us do at time 5. You should notice something for all of them... I want you to tell me a conclusion...there should be something that's mind blowing. Are they equal? **Stds:** No **One std:** Those for hydrogen are equal, for nitrogen is equal and for ammonia they are equal as well... **Sara:** Ok maybe I asked my question the wrong way. Can I show you something? Let me show you instead of saying calculate...When I look at this, what I should have said was for you to calculate the change between maybe, time and time 4 and between time 5 and 3. There should be something there. There should be a scientific discovery of some sort... **One std:** Scientific discovery? **Sara:** We could be able to discover something...calculate the rate between time 3 and time 4, and between time 5 and time 3. Rates, the difference... **One std:** Ai ma'am, what do we have to calculate? **Sara:** Difference in rates...so you will calculate rate right, at time 5 and then subtract it from time 4. And calculate the other one. You are subtracting the rates... Ok so you have concentration at time 5 right, if I'm saying between 5 and 4, we said rate is equal to change in concentration over change in time. So, I will take the concentration in 5 and subtract the concentration in 4 and then divide it by the time... **One std:** If I take the concentration at 5 and subtract the concentration at 4... **Sara:** So, what will the answer be? **Same std:** zero... **Sara:** Which means? **Same std:** The rate is not changing... **Sara:** The rate is constant...yes, that is what I wanted you to discover... So, you should have discovered that when you subtract, when you find rate, it is change in concentration over change in time. When you subtract the concentration at 4 and the concentration at 5, what is the difference? **Stds:** Zero **Sara:** And what is zero over a number? **Stds:** Zero **Sara:** Zero. And when we calculate the rate between time 5 and time 3, what is the change in concentration? **Stds:** Its zero... **Sara:** zero. Which means then, the rate is what? The rate is what? If I calculate the rate it is... **Stds:** It is zero... **Sara:** Zero, which insinuates that the rate is constant. So, the rate does not change, which means that the rate is constant. Are we aware? **Stds:** Yes	could in this case cause a misconception for the learners that the reactions have stopped. At this moment Sara could have introduced students to the correct equation used to relate the concentrations of reactants to the rate of reaction such as rate $=k[N_2]^x[H_2]^y$ **Qualitative in-depth analysis:** This segment is initiated by a learner question with respect to what one gets when they divide concentration by time. Sara passes the question to the class to which they respond "rate" which is the correct answer. This shows students' knowledge that is in place concerning rates, thus revealing their prior knowledge (LPK). Sara expands on the given response by specifically indicating that the concentration time graph is converted into the rate graph. The discussion involves asking students to calculate rate of all the reagents at an equilibrium position. Calculations are examples of symbolic representations (R). The calculations made are specifically done at an equilibrium point and Sara referred students to the value of zero obtained when doing the calculation to imply that the rates at equilibrium are not changing. The calculations are done to enforce students understanding of rate; an aspect of curriculum saliency (CS). This episode shows an interaction between three TSPCK components as displayed in the TSPCK map below. **A proficient TSPCK episode displaying linear and interwoven sequencing: WD-R/CS** 
Explaining why rates are calculated at a particular range: 55-60 mins ***Episode 14*** **One std:** When I calculate the rate, can I use different times, like for Hydrogen; I do it at time 2 and nitrogen maybe time 3 and then compare? **Sara:** When you calculate rate, it has to be at the same time. You have to use the same time for all. So, you are asking if I do it at time 3 and point 5. **Std:** Yes	**Overview:** To clear learner confusion on whether comparisons of rate can be done by calculating rates of reactants at different times, Sara explained that in order to make a proper comparison, the ranges in which the rates are compared should be the same. **Qualitative in-depth analysis:** The explanation is initiated by a learner confusion which could also be regarded as a misconception

Sara: It must be at the same time. When I want rate, I say change...ok delta...when I want the change in rate, I will say the change in concentration over change in time (writes the formula on the board). So, I take the concentration at time 5 and subtract it from concentration at time 3...so the rate between T=5 and t=3 will be equal to the change in concentration, over change in time. When we look at ammonia neh, what is the final concentration at time=5? It is two neh, minus...what is the concentration at 3? **Stds:** 2 **Sara:** 2 divided by 5 minus 3... What is the top answer? **Stds:** Zero **Sara**: Zero over 2... What is zero over a number? **Stds:** Zero	regarding calculation of rates (LPK). Sara explains this by demonstrating through calculations of rate (R). As she demonstrates this to the students, she explains that comparing the rates can only be within the same range. For example, calculating the rate of reaction between times 3 and 5 enables one to have a sense of the rate of reaction (forward and reverse) at those specific times (CS). The segment shows an interaction between three TSPCK components in an explanation that aimed at describing rate comparisons can be made. The episode is presented in the TSPCK map below. **A Proficient TSPCK episode with linear and interwoven characteristics: LPK/R/CS** 
<u>Evaluation: rates of forward and reverse reactions</u>: 60-65mins ***Episode 15*** **Sara:** I have an exercise for you that I found very interesting. So, question 1; Explain why the forward reaction rate decreases and the reverse reaction would increase as the system approaches equilibrium? **One std:** so, when the reactants are forming, the product rate increases, therefore the reactants will decrease... **Sara:** With reference to what? **One std:** The concentration time graph **Sara:** Yes, the concentrations versus time graph. So yes, you can add by drawing the concentration and rate time graphs neh...And what you can show is that from the two graphs that we did... this is just to go an extra mile, but what you said is correct whereby the concentration...did they speak of the concentration? So, as you are using the reactants to form products, it should be that the reactants' rate decreases, because now, you know these reactants are reacting to form products neh, so the rate decreases, decreases...and the products are initially not there, the rate is zero... initially the products were not there, and as time goes on, as these reactants react to form products, the graphs meet where equilibrium is established neh. So that is why with the rate graph, the reactants decrease, their rate decreases until equilibrium is established...It does not go to zero, please. And then, with the products, the rate increases, because initially there was nothing happening in the system, and then as the reaction occurs, occurs, occurs forming products, this means the rate increases, but there comes a point, you see, it's a curve. It cannot be a straight line, no. It initially starts with a high decrease in the rate at which reactants are used, and there is initially a high increase in the rate where the products are formed, and then the decrease, decrease, decrease, until equilibrium is established. So, what she is saying is correct. It is because the reactants are reacting to form products, that is why the rate is increasing for products at the beginning. And then you can just draw of the graph to show that these are the reactants, and these are the products. So, you use the rate versus time graph showing that the rates are equal at equilibrium. So, you should mention that the rates are equal at equilibrium. Did everybody get that? Stds: Yes	**<u>Overview:</u>** Sara expands on the learner response on the change in rates of forward and reverse reactions before reaching the state of equilibrium, by showing them how they can use the rate time graph to explain the changes. Although the initial reference was made to the concentration time graph, the explanation only focused on the rate time graph. **<u>Qualitative in-depth analysis:</u>** This teaching segment begins with a question posed to the learners requesting them to describe the rates of forward and reverse reactions before reaching a state of chemical equilibrium (LPK). Sara expanded on the response given by the learner, explaining how through use of the rate time graphs; students can be able to tell the changes in the rates of forward and reverse reactions. The explanation which pointed students to important elements to consider when describing the rates brought the component of curriculum saliency to the fore (CS), whilst the referred graphs are a form of representations (R). In her explanation of how rates change, she highlighted briefly that the rate of the forward reaction decreases until equilibrium is reached and added that the rate "does not go to zero". This could imply that the teacher remembered that from the calculations done in the previous segment, students may believe that the rates at equilibrium are at a zero margin which could imply that the reactions have stopped, which is a misconception that learners have regarding reactions at equilibrium. This then gave rise to a component of learner prior knowledge (LPK). The episode demonstrates three TSPCK components interactively used in an explanation with one component repeating as displayed in a TSPCK map below.

	A sophisticated TSPCK episode with interweaving components: LPK/R/CS/LPK 
Evaluation: What is dynamic chemical equilibrium: 65-69mins ***Episode 16*** **Sara:** The next question reads; what is dynamic chemical equilibrium? **One std:** First it is a state that occurs in a closed system, provided that the concentrations remain constant. The products remain constant and the reactants remain constant...eh, both the forward and reverse reactions take place at the same rate. The concentrations of the reactants and products remain constant at equilibrium. **Sara:** Thank you very much. That is what I was looking for. Remember we spoke about the state. Chemical equilibrium is a state that happens in a closed system whereby the forward and reverse reactions are equal neh ... and then we spoke about the concentrations at equilibrium staying constant...that is a now to suffice definition of chemical equilibrium, dynamic chemical equilibrium by the way. You must show that the rates are equal, and the fact that there is something that is always moving. There is never a static point within chemical equilibrium.	**Overview:** This is a segment that requires learners to express their understanding of what they learned about chemical dynamic equilibrium. **Qualitative in-depth analysis:** The episode begins with a learner question requesting students' understanding on what dynamic chemical equilibrium is from what has been discussed in this lesson (LPK). Sara affirmed the response given by the learner and expanded on it by reminding students that at dynamic chemical equilibrium, reactions are continuously happening, and never really stop. This emphasis is made because learners have a difficulty understanding the reversible nature of chemical reactions, more specifically that the two reactions (forward and reverse reactions) occur simultaneously (WD). The episode has two TSPCK components interacting evidently in an explanation given about chemical dynamic equilibrium as displayed in the TSPCK map below. **A basic interwoven TSPCK episode: LPK/CS-LPK/WD** 
Evaluation: The meaning of dynamic: 70-72mins ***Episode 17*** **Sara:** Ok. And then the next question...it says define the word dynamic and explain it to us... **One std:** Ok, dynamic means continuously occurring, therefore at equilibrium, the reaction has not stopped but is continuously occurring… **Sara:** Good. What you can add to that is that we do not, sometimes it can be that we do not see anything happening at the macroscopic level but at the microscopic level, the reaction is still taking place. Just that you cannot see at the macroscopic level, it may look as if nothing is happening, but at a microscopic level, something is happening…	**Overview:** The segment presents the meaning of dynamic, which then explains why chemical equilibrium is said to be dynamic. **Qualitative in-depth analysis:** On responding to what dynamic is a learner presented that it refers to the continuous nature of a reaction that never really stops (LPK). Sara added on this by emphasizing that the reaction is visible at a microscopic level, although macroscopically it may appear as though the reaction has stopped. The mention of microscopic and macroscopic level implicitly brings forth the aspect of representations (R), whilst the invisible nature of the reaction at a macroscopic level is what makes the concept difficult for students to understand (WD) This is a three component TSPCK episode as displayed in a TSPCK map below.

	A Proficient TSPCK episode with linear and interwoven features: LPK-WD/R 
Change in concentrations of reagents before chemical equilibrium is achieved: 72-75mins ***Episode 18*** **Sara:** So how do the concentrations of reactants and products change, ok as it approaches equilibrium, not at equilibrium? **One std:** When the reaction approaches equilibrium, the concentration of the reactants decreases because the reactants are being used up to form the products … **Sara:** Yes, or they are reacting to form products. **One std:** Ma'am I do not understand why the reactants are decreasing... **Sara:** So, they are decreasing because they are being used up, or the reactants are reacting to form products as equilibrium is approached... **One std:** So, are you saying that the concentrations are constant within this whole reaction... **Sara:** No concentrations are not constant throughout **One std:** It is constant at equilibrium **Sara:** Yes, at equilibrium **One std:** So here they are approaching? **Sara:** They are approaching. It is the first part of the graph, the one that is curved. You see that curve, that part is steeper, you see that part that is decreasing. Why is it decreasing? Because the products are being formed. Eh, the next one, concentration of products... **One std:** Eh, the concentration of the products increases because they are being formed from the reactants... **Sara:** Yes, do you guys get that? Concentration of products increases because they are being formed from reactants.	**Overview:** When asked how the concentrations of reagents change before reaching a state of chemical equilibrium, two students seemed to have a difficulty understanding the change. This then resulted in Sara using a graph to emphasize on how the changes occur. **Qualitative in-depth analysis:** This segment begins with a question requesting learners to describe the change in concentrations of reactants and products as the reaction approaches equilibrium; as aspect of learner prior knowledge (LPK). Two students demonstrated some form of confusion on this aspect, indicating their lack of understanding of this concept. Sara referred them to the graph and explained the changes, by indicating why concentrations are not constant before chemical equilibrium is achieved which is portrayed by the slopes on the graph. The graphs used as a form of representation (R), and the emphasis on which parts of the graph to focus on is as aspect of curriculum saliency (CS). The episode has three components that are evidently interacting in an explanation on change of reagents' concentrations before reaching state of chemical equilibrium. These components are displayed in a TSPCK map below. **A linear proficient TSPCK episode: LPK-R/CS** 
Explaining the rate of forward reaction from the beginning of a reaction: 75-82mins ***Episode 19*** **Sara:** The last question asked about the forward reaction rates. **One std:** Eh the energy of the reactants, eh the reactants have high energy level and as the reaction proceeds, the rate decreases... **Sara**: Ok... **Another std:** Ok, eh the rate of the forward reaction will increase because the graph is steep there (demonstrating a decrease in steepness with his hands) ... **Sara:** Of the reactants, it decreases... Ok, let me try and simplify it. Remember we did the concentration time graph neh? **Stds:** Yes	**Preview:** Explaining the rate of the forward reaction before reaching the state of chemical equilibrium using the concentration and rate time graphs. **Qualitative in-depth analysis:** The teaching segment begins with a learner prior knowledge (LPK) as Sara asks students to explain the rate of forward reaction before chemical equilibrium is achieved. The response given by one of the students is incorrect as the student argues that the reaction rate increases, the opposite of what really happens. To confront this, Sara referred students to the

Sara: Ok, when you look at the concentration time graph, you see that the rates of the reaction, eh not the rates, the concentrations of the reactants is decreasing neh? So, I told you that the rate graph comes from the concentration time graph, because rate is concentration over time. So if I calculate the concentration ... (draws the graph) ... so this is the concentration time graph. So, you know that these brackets represent concentration? **Stds:** Yes **Sara:** And then this is the rate, I put rate over time. If I have this, and this (draws lines to represent concentrations of reactants and products on the graph) ... So, if these are my reactants neh, we can see that if I calculate the rate here (the beginning of the reaction), and I calculate the rate here (right before equilibrium position), do you see that the rate has decreased? **Stds:** Ooooh... **Sara:** So, that's why, when you look at this graph (rate versus time), for the reactants, it decreases this way until equilibrium is achieved. So that is why I said these graphs work together simultaneously. This graph is derived from this one (rate from concentration time graph). So that is why we are saying the rates decrease for the reactants, because the reactants themselves decrease and then when you find the rate which is concentration over time, it should decrease. Do we all understand that? Is there a question? **One std: <u>When you are saying the forward reaction, do we mean the forming of products</u>**? **Sara:** Yes. Well, the forward reaction, when we have A Plus B producing C is the forward reaction, and the reverse will be C producing A Plus B. So, are we all clear on that? **Stds:** Yes	concentration time graph; a representation in this case (R), which they can use to determine the rate by looking at the change in concentrations of reactants. Sara's understanding of a conceptual teaching strategy (CTS) is demonstrated in her explanation as she used the graphs to explain the change in rates of forward reactions with reference to the change in concentrations of reactants with time (CS). The implication here was that with time, as more reactants form products, their concentration decreases, which then affect the rate at which they form products. The episode demonstrates an interacting between four components of TSPCK as displayed in the TSPCK map below. **A sophisticated TSPCK episode with linear and interwoven characteristics: LPK-R/CTS/CS** 
<u>Explaining the change in the rate of reverse reaction from the beginning of the reaction:</u> 82-86mins ***Episode 20*** **Sara:** Ok, and then on the reverse reaction rates? Ok, I just explained forward, so it is just the opposite of forward... **One std:** It will increase **Sara:** How? What causes the change if they asked? We need an explanation. Can someone else help? **Another std:** So, from what you explained there, when the reactants are being used, the rate is decreasing, so when products are being formed, from there it's zero because there were no products, so as more products are forming the rate is also increasing... **Sara:** Ok, you can see the game. Please relate the two graphs neh. From the concentration time graph neh, you can see that initially products are at zero...so the rate starts again at zero here. And when I calculate the rate, ok the concentration increases of the products right. So, when I calculate concentration over time which is the... **Stds:** The rate **Sara:** The rate will be higher than zero which means that it has increased neh. So, you can relate it to the fact that products are being formed, eh, reactants are reacting to form products... **One std:** So, the higher the higher the concentration the higher the rate? **Sara:** ...the higher the rate...so in math we say S over V (writes on the board). If S increases, the total that I get here will be high. If I increase V, this will decrease... **One std:** It will decrease... **Sara:** Yes, if I increase V, I will decrease...inverse relationships. We are going to apply some physics... **One std: <u>What do S and V stand for?</u>** **Sara:** They are just letters. I should have put concentration over time. When change in concentration increases, the rate increases. Time..., the reverse of that.	**<u>Preview:</u>** Explaining the rate of reverse reactions before equilibrium is reached, using concentration versus time graph. **<u>Qualitative in-depth analysis:</u>** The episode begins with a question raised by Sara requesting students to explain the rate of reverse reactions before chemical equilibrium is achieved to which they provided a correct response (LPK). Sara expanded on the response given by emphasizing on the importance of using the concentration and rate time graphs (R). She argued further that through calculation of rates from concentrations taken at the beginning and towards equilibrium can assist one in making an analysis of how the rates change across the reaction. The emphasis on where calculations can be made within the graphs shows that Sara knows the difficulty students can have in determining the rate at which a reaction occurs (WD). Further emphasis is made of the direct proportionality between concentration changes and rate (CS). The episode displays an interaction between four TSPCK components used to explain the rates of reverse reactions before equilibrium as portrayed in the TSPCK map below. **A sophisticated TSPCK episode displaying linear and interweaving interactions: LPK-R/WD/CS**



Introducing factors that affect chemical equilibrium: 86-93mins
Episode 21

Sara: "So, we said that when chemical equilibrium is achieved, we said that pressure, temperature and concentration are constant. So, what happens if these things do not remain constant? What if there is something that is disturbing the system, increasing or decreasing the temperature, adding or removing a concentration within a chemical formula or increasing or decreasing the pressure"? So, there is this scientist by the name of Le Châtelier's with a principle. His Principle helps us predict how the equilibrium would shift (a slide projected on Le Chatelier's principle) provided that there is a disturbance that takes place. So, Le Chatelier's stated that if the factors affecting a chemical reaction at equilibrium, namely concentration, temperature and pressure are changed or disturbed, then the equilibrium will shift so as to reduce or counteract the change. Is anything clear there? Do we understand what he is saying?
Stds: Yes
Sara: He is saying that if any of the three factors that I mentioned, the ones that we said must stay constant in order for equilibrium to stand undisturbed, and then the system will try to counteract that change by shifting. Because now if we disturb the system, we are no longer in equilibrium, do we understand that?
Stds: Yes
Sara: So, now the system will change in such a way as to oppose or counteract the change. Are we ok on that?
Stds: Yes
Sara: Ok, as I said before, there are three main factors that affect equilibrium. Those are temperature, pressure and concentration. You guys remember that concentration mainly has to do with aqueous solutions, and when we talk about pressure, the only thing that we can pressurize is what, it's gases. And then we talk about temperature. So, we will explore each and every one of them in greater detail. Ok, so I have a couple of questions...so I said here we use the Le Chatelier's principle to predict what will happen to a reaction in equilibrium if the three factors would change right. When counteracting this change, eventually a new equilibrium will be re-established. Do we all agree on that? If it is disturbed, it is then disturbed and then it gets re-established right. Ok, so when it is re-established, we will have a new set of concentrations for the reactants as well as the products and eh, in order for us to be successful in answering the questions that have to deal with this part of the concepts, I just have three questions that you must ask yourself with regards to answer questions that have to deal with this. So, the first one... 1. What causes the stress to the system?
One std: The stress?
Sara: Yes, the stress. So, the system is stressed by either concentration or..., so what causes the stress t the system? Ok, just put in bracket temperature, pressure or concentration. Question 2. What is the response of the system? (Use Le Châtelier's). 3. How does the system oppose the stress? (Identify whether the forward or reverse reaction will be favored). This will help you...
One std: So, you identify the...
Sara: Ok, with the first question, you need to identify from the question itself on the exam paper. You see that oh, the pressure is increased or decreased, the temperature is changed, or the concentration is increasing...That's the first question. You identify what is the problem, ok? And then with the second one we said that what is the response of the system? So, if I add more reactants, then that would mean that there would

Overview:

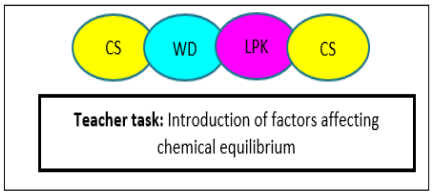
Identifying factors affecting chemical equilibrium, including the Le Chatelier's principle and providing steps to follow when a disturbance is added to a system that has reached equilibrium

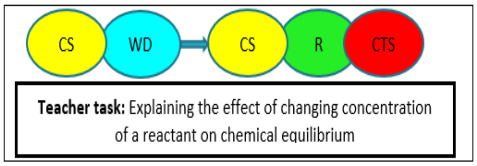
Qualitative in-depth analysis:

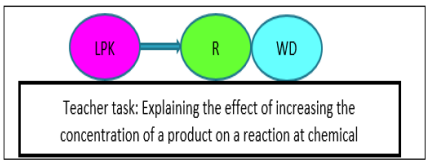
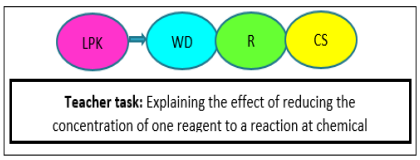
This teaching segment introduces the factors that affect chemical equilibrium; change in pressure, temperature and concentration. These are key concepts crucial to the understanding of the topic (CS). The effect of the disturbance is explained through an introduction of a Le Chatelier's Principle where a system always acts to counteract the effect of a disturbance. This aspect of the effect of a disturbance is not an easy concept for the students to comprehend (WD). This is seen in the emphasis that the teacher does, repeating the principle multiple times. Sara then reminded students that the effect of change in concentrations can only be considered for aqueous solutions, while pressure changes are applicable when dealing with gaseous molecules. This is related to what students should have learned in earlier grades; hence it is an aspect related to learner prior knowledge (LPK). She then provides learners with sequential steps to follow in deciding how a disturbance will affect an equilibrium position, bringing forth a different aspect of curriculum saliency (CS).

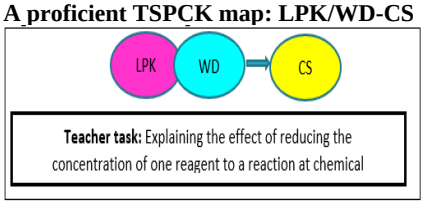
The episode shows an interaction between three different TSPCK components in an explanation with as aspect of curriculum saliency repeating. The interactions are demonstrated in the TSPCK map below.

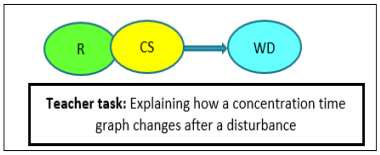
An interwoven sophisticated TSPCK episode: CS/WD/LPK/CS



be more reactants to react, which takes us to the next question, the third one, which reaction is favored, the forward or the reverse? The effect of this stress that you have added onto your system. So, are we good? **Stds:** yes	
<u>The effect of increase in concentration of a reactant:</u> 93-100mins ***Episode 22*** **Sara:** Ok, let us explore the effect of concentration. It says here that when a concentration of a substance is increased, the forward and reverse reaction rates...which means the overall reaction rate increases…which means there would be more effective collisions within the system, meaning the overall reaction of the system increases. Ok, but when the concentration of the reactant or product is increased, the equilibrium shifts away from the increase to reduce the amount of the added substance. Ok let me just explore it now neh ... So, I will use arbitrary reactions. So again, if I have my A Plus B (as she writes in the form of an equation on the board), forming C. If it was just (writes a single headed arrow), and you add more of A or B, you already know that the system is not at equilibrium. Do not even consider it. Do not use Le Chatelier's; he does not deal with things that are not in equilibrium. So, as I put in my beautiful double-sided arrow... So, I have A and B neh. Question 1. Add more of A. That is question 1. I have identified what a disturbance is. We said that we have added A neh. We have added more of the reactants, neh. And now I will use the Le Chatelier's principle to answer how the system will change neh. And Mr. Le Châtelier's said what? **One std:** The system will oppose the stress... **Sara:** To oppose that. So, when we are looking at this, if I add more A, what will happen to the system? **One std:** So, more reactants will react and then more C will form. **Sara:** …So now I have added more A onto the system, which means the concentration of this, will go up (A), which means this will go down (B), but this will increase (C).	**<u>Overview:</u>** Sara used an arbitrary equation **A + B↔C** to explain the effect of adding A onto the system. She emphasized by drawing back on the steps presented earlier on how to determine the effect of a disturbance. **<u>Qualitative in-depth analysis:</u>** The segment begins with an emphasis that whenever a concentration of a reagent in increased, the overall reaction also increases, as the increase affects the effective collisions happening within the reaction as a whole. An understanding of collision theory is essential for conceptualization of chemical reactions; an aspect of curriculum saliency (CS). Sara then continued by highlighting on the effect of a change in concentration of either a reactant or a product on chemical equilibrium; a concept considered as difficult for students (WD). As she is emphasizing on this effect, she begins first by cautioned students that the Le Chatelier's principle cannot be applied for irreversible reactions, as those reactions cannot reach a state of equilibrium (CS). She then continues her explanation by using an arbitrary chemical equation (R), with reference to the steps discussed earlier in the session on how to work out the effect of adding a stress to the system that has reached a state of equilibrium which forms a conceptual teaching strategy (CTS). The episode shows an interaction between four TSPCK components as displayed in the TSPCK map below. **A Sophisticated TSPCK episode with interwoven and linear features: CS/WD-CS/R/CTS** 
<u>The effect of increasing the concentration of a product:</u> 100-103mins ***Episode 23*** **Sara:** So, what will happen if I increase C? What will happen to the system? …which reaction will be favored? **Stds:** The reverse **Sara:** The reverse neh and the overall reaction as I said will increase. The rate of the overall reaction will increase, but the reaction that is favored the most is ... **Stds:** It is the reverse reaction... **Sara:** The reverse reaction because the system is trying to do what? **Stds:** oppose... **Sara:** Oppose this added C that I added in my system. Again, what will happen is that C will increase, but everything this side will now increase (A and B), because C is the one that breaks up to form A Plus B. But if there was C and D, D would decrease, C would increase, A and B would	**<u>Overview:</u>** Explains how the system will react to the change by emphasizing on the changes in concentrations of A, B and C, as a result of change in C. **<u>Qualitative in-depth analysis:</u>** The teaching segment begins with the teacher probing learners on the effect that increasing the concentration of a product has on a reaction that has reached chemical equilibrium (LPK). With reference to the arbitrary equation (R) mentioned prior to this discussion, the teacher explains why an increase in the concentration of C (a product) would result in an increase in the concentrations of A and B (the reactants) because the reverse reaction that reduces the added substance is favored (WD).

increase. So here if I add more of C, C will increase, A increases and B increase.	An interactive use of three TSPCK components is seen in this episode as displayed in the TSPCK map below. **A Proficient TSPCK episode with linear and interwoven features: LPK-R/WD** 
<u>The effect of decreasing the concentration of a reactant:</u> 103-106mins ***Episode 24*** **Sara:** Ok, so now if I remove B, what will happen? **One std:** The reverse reaction will be favored. More C starts to react to form A and B. **Sara:** More A and B, yeah... **Another std:** So, the reverse reaction is favored... **Sara:** Yes. But the overall reaction will be what? **One std:** Decrease **Sara:** The rate of the overall reaction will decrease but the reverse reaction will be favored, because we are trying to counteract this state of removing B... we are missing B in the system. There is not enough B in the system, so C must react to form B and A, yeah... **One std:** I just don't understand how the reverse reaction is favored because in the first one we increased A, and it favored the forward reaction, then we increased C and the reverse was favored. But now why is it not the forward that is being favored? **Sara:** Ok, so B is now missing. There is not enough B in the system, so we are short of Bs. So, the system must shift in such a way as to make more Bs, and the only way to make B is by having this reaction occur (the reverse), because if we are saying A and B, the forward reaction is being favored, there is already a shortage of B. So how can you make B when you already do not have sufficient B to mix A. So, C will have to react neh, to form A and B, to counteract the stress of not having enough Bs. So that is what happens to the system. The system will shift to the left neh, the reverse reaction. Shifts to the left or shifts to the right. It is the same...well not same. You know what left means...if you say shifting towards right, you mean shifting towards C, if you are saying it is shifting to the left, you are saying it is shifting towards A and B. Or you can say the forward or the reverse reaction is favored. Rather put both because sometimes in the exam they ask you, so we have this system, and they are like, shifts to the right. So, you must know that when it shifts to the right it means you are going towards your right. Shifting, you are moving to the right. And if we are saying that we are shifting to the left, we mean that we are moving towards left. You get that? **Stds:** Yes	**<u>Overview:</u>** Explains the difference in change of concentrations of reagents when the concentration of one reagent is increased versus when it is removed from the system with respect to the Le Châtelier's Principle. Emphasis is done with reference to the arbitrary reaction used as an example. **<u>Qualitative in-depth analysis:</u>** This begins with a question-and-answer method on the effect of reducing the concentration of a reactant on an equilibrium position (LPK). Sara explains further the effect that this will have on equilibrium by stressing that the system should act so as to replace the removed substance, thus counteracting the change (WD). When one student demonstrated a misunderstanding by asking why the change differs from what was discussed earlier, Sara gave a more explicit explanation with respect to the Le Châtelier's principle. She evidently pointed out that because the concentration of one reagent has been removed, the system will favor a reaction that produces more of it, unlike when the concentration of a reagent is increased where the system would instead want to reduce the added substance (CS). The explanation Sara gave repeatedly used the symbols from the arbitrary chemical reaction (R). The episode shows an interactive use of four TSPCK components as displayed in the TSPCK map below. **A Sophisticated TSPCK episode with linear and interwoven features: LPK-WD/R/CS** 
<u>The effect of decreasing the concentration of a product:</u> 106-108mins ***Episode 25*** **Sara:** Ok again, what if we remove C, let us start with the overall reaction. What happens to the overall reaction? **Stds:** The reaction decreases... **Sara:** It decreases. The rate of the overall reaction decreases. Now we are looking at specifics. Which reaction will be favored, forward or reverse? **Stds:** Forward	**<u>Overview:</u>** Sara probes for further understanding of the effect of change in concentration of a reagent to a reaction that has reached chemical equilibrium; with the focus on decreasing the concentration of a product. **<u>Qualitative in-depth analysis:</u>**

Sara: So the forward reaction will be favored because we need to form more Cs because we have a shortage of our C within our system. So the forward reaction or the shift that is towards the right is favored. Do we all agree there? **Stds:** Yes **Sara:** Yes. **One std:** Ma'am when you say it favors the forward reaction, you mean it favors the C? **Sara:** Yes. Well, the forward reaction, when you look at the reaction, it is like this...so A Plus B forming C. So, when we break it down, A plus B forming C will be the forward reaction. And the reverse reaction is C forming A and B. So, that is how we came with the forward reaction. The forward reaction, you look from your left to your right. The reverse reaction, you look from your right to your left. The way these reactions, sometimes you can just put, eh, write the reaction this way...C giving A Plus B (using a double headed arrow). The forward reaction is C to A and B, and the reverse will be A Plus B forming C (writes the equations on the board). Look at even how you write. You move from your left towards your right. You move from left towards your right. And that is why I said that when the forward reaction is favored, we can say that the shift is towards the right, or when the reverse is favored, the shift is towards the left.	Sara begins by probing on what impact the decrease on concentration will have on chemical equilibrium state, which taps on learner knowledge (LPK). Sara adheres to the response given and expands further explaining why the forward reaction that produced the removed substance is being favored (WD). The explanation given by Sara triggers a learner question with regard to which reaction is the forward reaction (LPK), to which she explains using an arbitrary reaction of A and B forming C as forward and C breaking into A and B as a reverse reaction. This is an aspect of curriculum saliency as it helps the learner with the interpretation of a chemical equation; an important aspect for understanding any chemical reaction (CS). Three different components are interactively linked in this episode as shown in the TSPCK map below. **A proficient TSPCK map: LPK/WD-CS** 
Emphasis on the reaction of chemical equilibrium as a result of a disturbance: 108-110mins **Sara:** I think you guys get the idea of how the shift occurs; a system acts to counteract or oppose this thing that has been induced within the system, neh. Also, this is just an addition of what I was saying; it says here, if the concentration of the reactants or products is increased, the equilibrium shifts away from the increase to reduce the amount of the added substance. The reaction rate that reduces the substance that has been added proceeds faster. So, the one that is added, which has something added proceeds faster than the one that is not added. That is easy to explain neh. The second one is just the opposite of what I was saying, when the concentration of a substance is decreased, which means that I have removed some of the substance, the forward and reverse reaction decrease. So that means the overall rate reaction decreases, but when the concentration of the reactants or products is decreased, the equilibrium shifts towards the decrease to make more of the removed substance. Are we all in agreement? **Stds:** Yes	**Overview:** Sara emphasizes of how the reaction reacts to the effect of a disturbance, by shifting away from a disturbance, which in this case, the added or removed concentration of a reactant or product. **Qualitative in-depth analysis:** In this segment, Sara puts more emphasis on the effect that increasing or decreasing the concentration of a reactant or product has on chemical equilibrium. This is a concept that learners find difficult (WD). No other component is evident in this segment. Therefore, this is not an episode.
Describing a concentration time graph from change in concentration: 110-115mins ***Episode 26*** **Sara:** Ok let me show you this. So, this is the graph at equilibrium. So, as you can see, equilibrium has been reached at this point neh (referring to the graph she drew earlier). And then something happens that causes the concentration of Nitrogen dioxide to increase (shows an increase on the graph). So now we are going to see how the system will react. If the reaction, eh if I increase NO2, this means the products will increase... then equilibrium is established neh. And then with this one, it would decrease because the reactants are being used to form products (presents that on the graph). **One std:** They cross? **Sara:** Yes, they can cross, it does not matter. This is concentration, concentration they can cross...	**Overview:** She explains that a sharp increase happens only for the added substance, whilst the products show a gradual increase because a reaction is not as rapid as when something is added. She then displayed a graph that depicts how the graphs have changed after a distress. **Qualitative in-depth analysis:** Sara begins the discussion with a display of a graph (a Representation-R) portraying a reaction at equilibrium as she explains how the change in concentration affects a state of equilibrium (CS). The explanation triggers a learner question which provides a sense of difficulty on how the graph changes after a disturbance. This she explains with an emphasis on what causes a sharp

One std: Eh, the products, does the line of products also go straight like that one of the added substances? **Sara:** What do you mean? **Same std:** Do you see that line you drew (referring to a sharp increase line on reactants), does it continue like that... **Sara:** Why it increases, so we increased NO2, and the system will now change or oppose this added increase. So now these are reactants, there was a sharp increase of them. Now they are going to be used up to form products. But as I am forming products, then the products must increase. They are not sharp like the reactants. It is like taking NO2 and putting it in the system, but it does not mean that there will be a sharp increase in my N2O4 (product). So, this is how it will look. So where is chemical equilibrium achieved? **One std:** draws a line... **Sara:** Good. You know why I put them this way (one constant before another), I wanted to show that the fact that this one has achieved equilibrium does not mean that the other one has. Equilibrium is achieved when both of them have constant, or when all the reactants and products in the system, concentration remain constant. So, the fact that this one has achieved equilibrium does mean that the whole system is in equilibrium itself...	increase a sharp increase when something is added as opposed to a gradual increase of what is produced when the added substance reacts (WD). The episode shows an interactive use of three TSPCK components in an explanation as displayed in the TSPCK map below. **A Proficient TSPCK episode with linear and interwoven features: R/CS-WD** 

Even though Sara's lessons portrayed the most TSPCK episodes compared to Noma and Lerato's, overall, all the three PPSTs' lessons revealed the highest number of high-quality TSPCK episodes, ranging between proficient and sophisticated types. This gave a sense of high-quality explanations displayed by the PPSTs in their teaching. An overview of the three PPSTs' TSPCK profiles is presented in Figure 6.3.

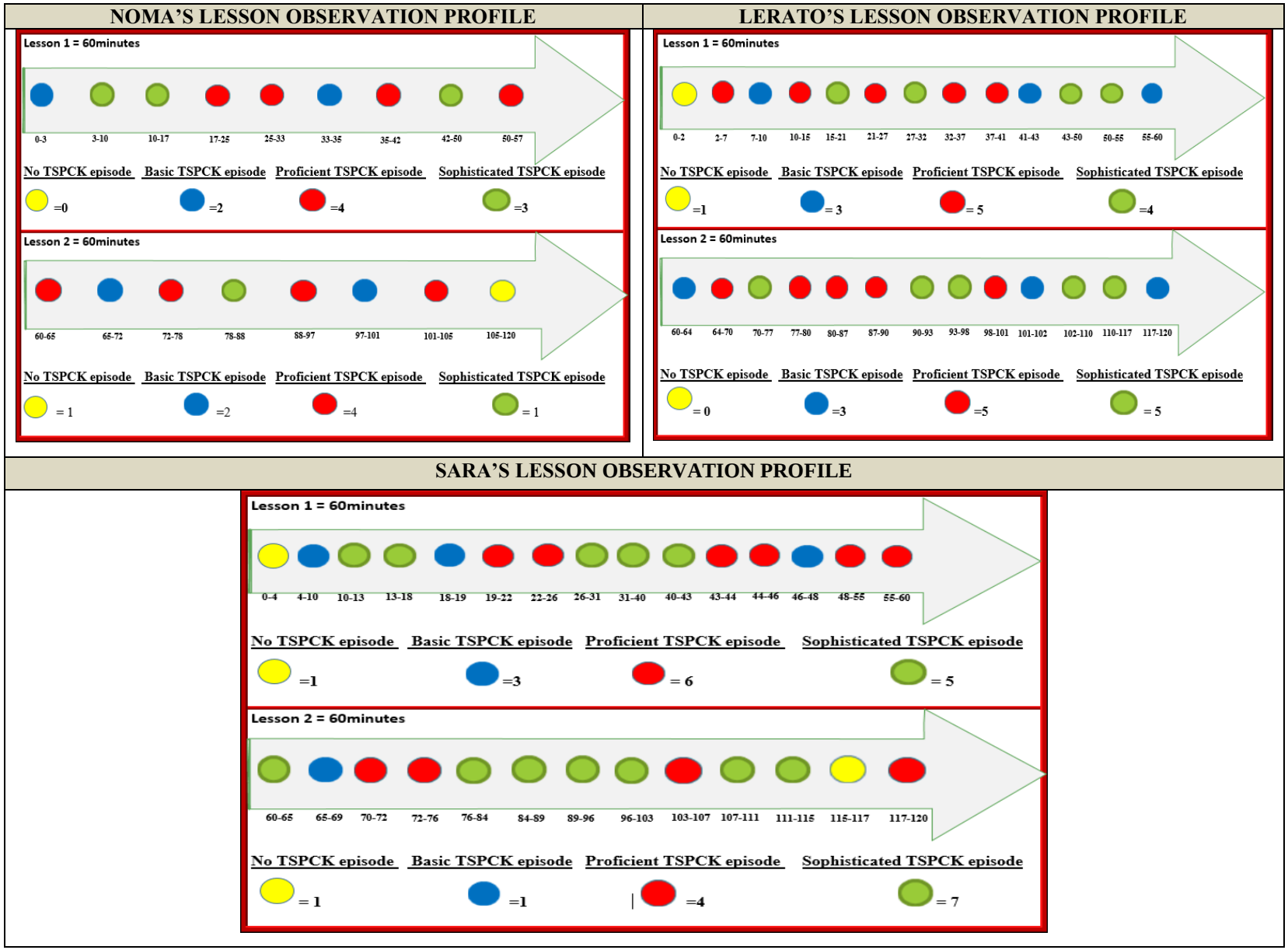


Figure 6. 3: PGCE PSTs' TSPCK profiles displaying their lesson sequence

The numbers above show that overall, the PPSTs had, on average, about the same number of TSPCK episodes in their first and second lessons, respectively. In addition, all the 3 PPSTs had the lowest number of basic TSPCK episodes compared to those at proficient and sophisticated levels. All the three types of episodes were spread across the two lessons, except for Noma whose four sophisticated TSPCK episodes are predominantly depicted in her first lesson. Out of 9 TSPCK episodes from Noma's first lesson, 2 were basic, 4 were proficient and 3 sophisticated. On the other hand, 4 proficient and 1 sophisticated episode were identified in her second lesson, making it generally proficient. Overall, the PPSTs episodes were predominantly proficient and sophisticated, with Sara and Lerato displaying the highest number of sophisticated episodes. The dominating episodes in the PSTs lesson explanations could be indicative of their TSPCK quality observed in their ability to interactively use at least three components in their teaching of Chemical Equilibrium and thus, categorizing their enacted TSPCK at proficient and sophisticated levels. The findings are elaborated in the sections that follow.

6.3. The Findings

The following features are identifiable throughout the PPTSs TSPCK lesson profiles; 1. The episodes are complex in the nature of their component interactions and are idiosyncratic; 2. The episodes in the actual teaching of Chemical Equilibrium were higher in number and more complex than those reflected in the PPSTs' lesson plans; 3. Some lesson episodes were triggered by students' questions and or responses to the questions asked by the PPSTs. 4. The teaching segments that involved explaining difficult concepts and or addressing common learner misconceptions were more complex, with interplay of three or more TSPCK components.

6.3.1. Revealing the complex and idiosyncratic nature of TSPCK component interactions

The quality of PCK (TSPCK in this study), is determined by the coherent interconnectedness between the components (Park & Chen, 2012).The complex and coherent interactions seen in one's teaching is evidence of their developing PCK/TSPCK (Mavhunga, 2018; Park & Chen, 2012). The PPSTs episodes were overly dominated by episodes displaying either an overlapping fashion, or those having both a linear and overlapping sequences. Only two similar basic TSPCK episodes by Lerato had a linear sequence; (LPK-CS), whilst the rest of the basic episodes were interwoven. None of the proficient and sophisticated TSPCK episodes were observed to display only a linear

form of sequencing. For example, an episode that had an interplay between three components such as LPK, R and WD in the same order can have them interact in four different ways; LPK-R/WD, as observed in Noma's episode 9, LPK/R/WD in the case of Sara (her episode 10) and LPK/R-WD or LPK-R-WD which were not seen in any of the PPSTs' episodes.

As displayed in Table 6.8, out of 67 TSPCK episodes identified in the lesson observations of the three PPSTs, only seven were found to share similar characteristics, in terms of their nature of ways in which the components interact. This proves the idiosyncratic nature of the component interactions when concepts are being explained. That although the PPSTs taught the same content, their component interplay still varied from one PPST to another, based on what and how they wished to emphasize the concept being explained. The interplay of components differed even when the same concept was explained.

Table 6. 8: Overview on the nature of TSPCK episodes and component interactions from the PPSTs lessons

PGCE PST	Episode type and nature of component interactions			Total lesson episodes	Total episodes of similar nature
	Basic/Simple	Proficient	Sophisticated		
Noma	R/CS LPK/CS CS/WDx2	WD/LPK/R R/LPK-WD×2 LPK/WD/R LPK-R/WD R/LPK/WD LPK-CS/R R/WD/LPK	LPK/R/CS/R LPK-R/CS/WD/R/LPK CS/LPK-CS/WD R/LPK-CS/WD	16	6
Lerato	R/CS CS/R CS/WD LPK-CS WD/R WD/CS	R/CS/WD×2 CS/R/LPK LPK-CS/R×2 CS/R/CS LPK-R/WD LPK-R/CS CS/WD/R R/LPK/WD	R/LPK-CS/WD/R CS/R-WD/LPK/CS WD-R/CS/LPK CS/WD/R/CS LPK/R/WD/LPK LPK-CS/R/WD LPK/CS/R/WD CS/R/LPK/R/WD WD/CS/LPK/R	25	6
Sara	CS/LPK×2 R/CS LPK/WD	R/LPK/WD WD/R/LPK LPK/R/WD CS/WD/LPK LPK-R/CS×2 LPK/R/CS LPK-R/WD×2 LPK/R-CS R/CS/WD	LPK/R/CS/R CS/LPK/R/LPK/WD LPK/CS-R/WD LPK/WD/R- R/LPK/CS/CTS LPK/R/WD/CS LPK/R/CS/LPK LPK-R-CTS/CS LPK-R/WD/CS CS/WD/LPK/CS CS/WD-CS/R/CTS LPK-WD/LPK-R/CS	26	4
Similar episode	R/CS CS/WD	LPK-R/WD R/LPK/WD LPK-CS/R R/CS/WD	LPK/R/CS/R	67	7

The highlighted episodes presented in Table 6.8 are common in the PPSTs teaching segments. For example, under the proficient level, four episodes are common for the PSTs, as summarized in the last row under "similar episodes". With only a few episodes of a similar nature, this could be viewed as evidence of the complexity and idiosyncratic nature of PCK component interactions.

Explaining reversible reactions

The episodes below are extracted from two PPSTs' lesson profiles when Lerato and Sara were explaining the reversible nature of the reactions. Although the two PPSTs were explaining the same concept, the nature of their explanations, and hence the interplay between the components, differed. Both PPSTs however, used the same components in their explanations, as displayed by the shorthand format episodes **CS/LPK/R/LPK/WD** by Sara (episode 3) and **CS/R-WD/LPK/CS** from Lerato's explanation (episode 6). Each TSPCK episode has four different interacting components: LPK, CS, R, and WD, categorizing them both as sophisticated episodes. The sequence, the nature of component interactions and the emphasis made by each of the PPSTs were different. Sara's episode has components interacting in an interwoven fashion, with a component of LPK evidently repeating. On the other hand, Lerato's episode displays both linear and interweaving characters with a component of CS also evidently repeating.

Before describing reversible reactions, Sara began in episode 1, by providing the learners with the lesson objectives and the sequence of the lesson, which was a two-component episode (**CS/LPK)**. This was followed by a sophisticated episode **(LPK/R/CS/R)** that focused on reactions that go to completion and referred to as irreversible reactions, leading to a sophisticated episode 3 on reactions that do not go to completion (reversible reactions).

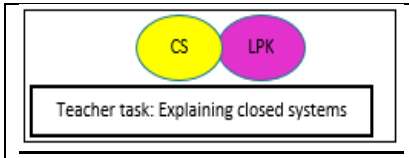
On the other hand, Lerato's lesson began with a proficient episode **(R/CS/WD)** where he discussed the collision theory that assisted the learners with understanding how chemical reactions occur. The discussion on collision theory, which included the use of a simulation, happened in four consecutive episodes in the order: **R/CS, CS/R/LPK** and **R/LPK-CS/WD/R**. Following this, Lerato introduced the types of systems in episode 5 (**LPK-CS/R).** This then led to episode 6 on the reversible nature of chemical reactions.

Another interesting discovery from the above interpretation is the difference in approach when introducing the concept of reversibility of chemical reactions. In the end, the purpose was for the

learners to understand the reversible nature of chemical reactions. This shows that each person's understanding of a concept extensively influences their approach to teaching it (Malcolm, 2018).

The excerpts that follow provide a detailed expression of how teaching the same concept can provide extremely different episodes and component interactions. Both PPSTs were introducing, for the first time, the type of system needed for reversible reactions to occur in, which is a closed system.

Sara's episode 4: *A basic TSPCK episode*	**Lerato's episode 4:** *A sophisticated TSPCK episode*
Describing a condition for reversibility- a closed system: 18-19mins **Sara:** "And then the last point that I pointed there is that a reversible reaction can only take place in a closed system. And then now, that is another word that I have come up with, a closed system. What is a closed system?" **One std:** It is a system whereby the contents of a reaction are not allowed to react with the surroundings. **Sara:** True. There is nothing that I put in and there is nothing that comes in. So basically, that is what eh, some of the elements that go into explaining what chemical equilibrium is. **Qualitative in-depth analysis:** A condition necessary for reversibility of reactions "a closed system" is explained; an evidence of curriculum saliency (CS), drawing on learners' own understanding of the concept (LPK). **A basic TSPCK episode: CS/LPK**	**Open and closed systems: 15-21mins** **Lerato:** Ok, maybe we should start here. So, I want you guys to in your pairs, right? I want you guys to talk about, to discuss two things right. What happens and what is the difference between you boiling water when there is a lit, and you boiling water when there is no lit? So, you put a pot on the stove, you pour water, then you boil it, you do not put a lid on top. Then the second situation, you put a lid on top and let's assume that the lid is airtight. It does not do funny things. So, you even extra seal it, you extra seal. So, discuss amongst yourselves for five minutes as I prepare this then we will talk. ... Right, we are back, so what did you guys at the back discuss? One std: Ok, eh, when there is no lid eh... **Lerato:** When there is no lid? **Same std:** Yes. When there is no lit, we lose water... **Lerato:** We lose water, right? **Same std:** The water will evaporate **Lerato:** yes... (writes it on the board) **Same std:** Eh, when there is a lit, it will not evaporate... **Lerato:** If there is a lit? **Same std:** yes Lerato: If we have a system that is open, what happens? **One std:** We lose **Lerato:** We will lose right? So, in general chemistry language we say we lose mass, right? So, we are going to loose of whatever we have in there, right? Eh, it does not necessarily have to be lost to, it doesn't necessarily have to be lost through evaporation, by evaporation or anything like that. but because of what we saw that there are constant collisions that are happening right, if you have the liquid, then the temperature outside also has, plays a role in evaporating some of it out. If it is a gas, then obviously it is going to escape right? So, we know, in an open system, we are going to lose staff. This means we can never really achieve that whole converting back that he was talking about. Which is very important to the concept of chemical equilibrium? Secondly, in a closed system, we are not losing anything right. So, which means, you keep getting this whole process of your staff are turning back into other staff, and then staff is turning back to other staff right? This is actually very powerful because it means if you think about it, if we are in a closed system our reaction never really stops. It never stops. Even if looks like it stopped, it doesn't stop. Which is quite interesting because you know, generally you will see a beaker and say, ah no, that thing was blue, now it's pink. So, it



stopped this thing right. But because of what we know from collision theory right, the collisions become less and less likely to happen. So, which means your products that are forming are not big enough to show that huge change for you to say, ah no there is some bluish color there...So remember we are talking about particles here. Particles are super small, very small. So, you can't even say, ah, no three of them here, we have got 10 there...you know. And that is what is important. It's that, because that happens at a microscopic level, you can't see that observable change. You can't see that it is happening, but it is happening right? Because we know that in a closed system, right, that there is this continuous rearrangement back and forth with reactants forming products and products back to reactants. It is however relevant to note that when we are dealing with water, water is not actually, there is no chemical reaction when dealing with water. Water is still water. It is just water in another phase. You know this, it is still water. When we look at closely, specifically other chemical reactions that are actually having a chemical reaction right. So, this is not a chemical reaction. It is just a physical reaction. But it is important that we use it to sort of understand and get our heads around what exactly happens in a closed system and sort of have a basic idea of what happens in an open system.

Qualitative in-depth analysis for Lerato's episode:

The segment begins with a scenario of boiling water in a closed versus an open pot (R) which the learners are to discuss in their groups and give feedback (LPK). Lerato goes on to introduce learners to the types of systems open and closed, and their characteristics in terms of loss of mass by open systems, and the opposite for closed systems (CS). Further emphasis by Lerato pointed out the continuous nature of reactions in the closed systems that never end, where reactants rearrange forming products, whilst at the same time products react back into reactants (WD). His explanation also highlighted that the reversible nature of the reactions can only be seen at a microscopic level (R).

A Sophisticated TSPCK episode: R/LPK-CS/WD/R

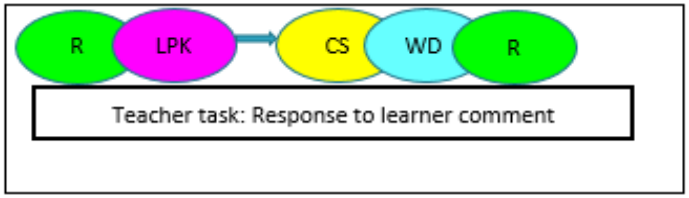


Figure 6. 4: Extracts on the actual teaching of the types of systems

6.3.2. TSPCK episodes portrayed in the lesson plans versus those in the lesson observations

The refined consensus model (RCM) of PCK has characterized an enacted PCK (ePCK) as drawing from 3 sets of knowledge, from planning to teach, the actual teaching and reflecting on the lesson (Carlson & Daehler, 2019). Planning for a lesson is therefore an especially important part of teaching as the teacher is able to sequentially put the concepts down in a way that learning, and understanding can be maximized. It was then crucial to compare that which was planned, and how the actual lessons evolved. It has however been shown that what has been planned does not always come out as anticipated in the classroom due to some lesson intricacies and other possible filters (Gess-Newsome, 2015) which can then affect the direction and sequencing of the lesson as well as how explanations are made to some extent.

The PPSTs' lesson plans were sectioned to include all the five TSPCK components. The episodes were extracted mainly from four different sections of the lesson plan, namely *(a) the* ***summary of important content which is under a component of curricular saliency****, (b)* ***the use of representations*** where the PSTs are likely to describe how their choice of representations would be used, *(c) the* ***concepts that are difficult to teach and understand*** and *(d)* ***the sequencing of the lesson which also involves the conceptual teaching strategies*** to be employed in the teaching of important concepts.

Table 6.9 gives an overview of the PPSTs TSPCK profiles reflected in their planning for the teaching of Chemical Equilibrium. It shows that the lesson plans consisted mainly of basic TSPCK episodes with an interaction between two TSPCK components evidently used in the explanations made.

Table 6. 9: Types and nature of episodes in lesson plans

PPST	Basic	Proficient	Sophisticated
Noma	**WD/R** **CS/WD**	**CS-R/WD** **CS/R/WD** **CS-WD/R**	**CS-R/WD-R/CS**
Total	**2**	**3**	**1**
Lerato	**WD/Rx2** **R/CS** **CS/R**	**CS/R-CS** **R/LPK-CS**	**CS/R-LPK/WD/R**
Total	**4**	**2**	**1**
Sara	**CS/WD** **R/LPK** **CS/R** **LPK-WDx2** **R/WDx2** **LPK-CSx2**	**CS/WD/LPK** **R/WD/LPK**	**CS/LPK/R-R/WD** **CS/LPK-R/WD/R/R/LPK**
Total	**9**	**2**	**2**

Although lesson plans had TSPCK episodes predominantly categorized at a basic level, the actual lessons themselves comprised an increased level of TSPCK interactions at proficient and sophisticated categories, as portrayed in Tables 6.6 and 6.8. The episodes that are identified in the lessons have been perceived as more complex than those reflected in the lesson plans provided by the PPSTs. Also evident is the fact that a single episode identified on the lesson plan grew into a cluster of episodes in the lesson, as the discussions progressed, hence the increased number of TSPCK episodes during the actual enactment.

The case of Noma

Overall, a total of 6 episodes were identified from the various sections of Noma's lesson plan, two of which were basic, 3 of a proficient type and 1 a sophisticated episode. Conversely, the actual lessons observed had more episodes; a total of 16 which comprised 4 basic episodes, 8 developing and 4 that were of a sophisticated nature.

Four of Noma's TSPCK episodes were extracted from a section under the "summary of most important content knowledge". First it was WD/R, an episode that introduces the reversibility of chemical reactions. The second episode, a proficient episode, is based on the factors that affect Chemical Equilibrium. This involved an interplay of three components CS, R and WD, where curriculum saliency is linearly linked to a representation component that overlaps with the aspect

related to the difficulty of the concept, CS-R/WD. Another basic episode that described the Le Chatelier's principle, followed with an overlapping interaction between CS and WD. The summary ends with a detailed description of the effect of the change of pressure on a reaction that is at equilibrium. Three components interact in an interwoven format in this section: CS/R/WD. The fifth and sixth episodes were identified under sequencing and conceptual teaching strategies.

Figure 6.5 pictorially displays the difference in the number of episodes portrayed in Noma's lesson plan versus her actual classroom teaching of Chemical Equilibrium.

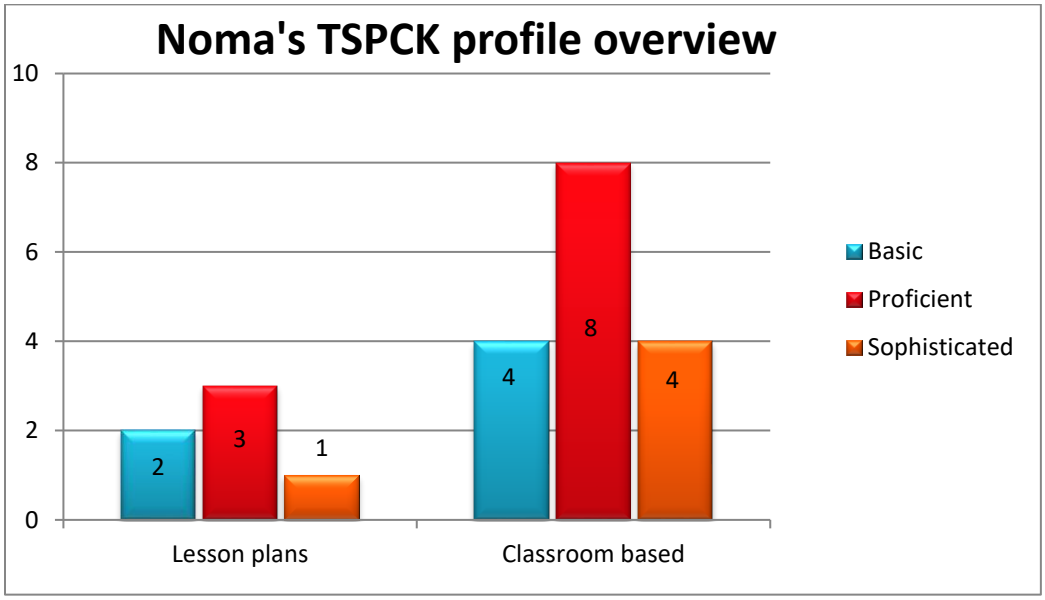


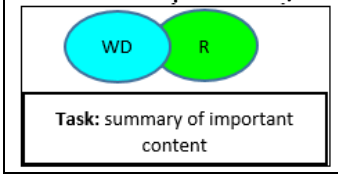
Figure 6. 5: An overview of Noma's TSPCK; lesson plans versus lesson enactment

The excerpts below are used to illustrate the nature of classroom TSPCK component interactions and the resultant complexity of the emerging TSPCK episodes, when compared to those revealed through lesson planning which are focused on the same concept of reversibility of chemical reactions that undergo a Chemical Equilibrium process.

<table>
<tr><td>Lesson plan: Summary of important content knowledge</td><td>Lesson enactment: The reversibility of chemical reactions</td></tr>
<tr><td>The idea of reversibility of reactions. Where a reversible reaction is when the reactants react to form products and products also react to form the reactants. And this is indicated by a double arrow.</td><td><u>Lesson 3: 10-17mins</u>

Noma: … Ok, let us talk about reversible reactions…for example, where do you think this reversibility takes place? What kind of a system?
One std: Open
Noma: Ok, you are saying open. Why are you saying open?
Same std: Eh, ma’am gases can be compressed to maybe, eh let us say water, it can be converted into gas, and later into liquid…
Noma: Do you think it is an open system?
Same std: I think so because it happens in …
Other stds: No, it is a closed system
Another std: I think it is in a closed system because it’s in a controlled environment, so you know what reacted and you can reverse that.
Noma: And you can reverse that right… So, give me a definition of what reversing means in chemistry…
One std: It is maybe when a reaction is undone…
Noma: Let us say you have two reactants reacting, where A and B react to form C and D, then C and D also react to make A and B. Do you see? (Representing the reverse with a two headed arrow on the equation). I know from grade 9, you were only doing it like this neh (draws a single headed arrow). Where you find that most of your reactions would be going only in one direction. So, when a reaction happens in a closed system, reactants combine to form products, and products also react to form back the reactants. Those types of reactions are called reversible reactions. They are reversible because reactants combine to form products, and products form and form, and those products also react and form reactants. So, a simple scenario can be a case of water. You have got your class beaker, pour your water and cover it (doing hand demonstration). It will evaporate but it doesn’t go any further because it can’t escape. The gases can’t escape. There is cooling that happens, and then it drops off as liquid water. The cycle continues and continues and never ends. After some time, the reaction will reach chemical equilibrium. Ok, this does not only happen with water. It happens with a lot of reactions too.</td></tr>
<tr><td><u>Qualitative in-depth analysis:</u>

The segment has Noma explaining what reversible reactions are, and what feature portrays any reaction reversible, which is the use of a double headed arrow (R) on a chemical equation. The reversible nature of chemical reactions is a difficult concept for students to understand (WD).

Two components are distinguishably at interplay in this excerpt.
A basic TSPCK episode: WD/R
</td><td><u>Qualitative in-depth analysis:</u>

Noma introduced the concept of reversibility by tapping on students’ understanding of what reversible reactions entail (LPK). She then continued by referring students to the chemical equations/reactions that were discussed earlier in the lesson. Chemical equations are examples of symbolic representations (R), whilst reversibility of reactions is a difficult concept for learners (WD). She puts an extra emphasis that reversibility happens in closed system; an aspect of curriculum saliency (CS). Providing a scenario of water evaporating and condensing back to a liquid (R) to emphasize that this is a continuous process where one reaction does not have to stop before the other begins. This is evidence of learner prior knowledge in the form of a misconception (LPK).

A four component TSPCK episode evidently interacting in an explanation as displayed on the TSPCK map with LPK linearly linked to other interwoven components.

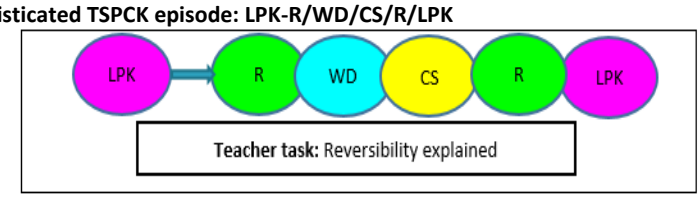
A Sophisticated TSPCK episode: LPK-R/WD/CS/R/LPK
</td></tr>
</table>

Figure 6. 6: Noma’s lesson plan extract and enactment on reversibility of chemical reactions

In the excerpts above, the planning of teaching on reversibility of chemical reactions gave rise to the basic TSPCK episode (WD/R). The actual classroom teaching of the same concept, however, is more complex, as four different components are evidently interacted in an explanation and two more components are repeating in a distinguishable manner, LPK-R/WD/CS/R/LPK. What Noma had planned to put across, which was shown through an interaction between WD and R, thus forming WD/R, is reflected in the expanded lesson, although the interaction is reversed and begins with a representation, thus showing R/WD instead. This provides a sense of an expansion on what was planned.

Following this is a further analysis revealing the clustered nature of episodes formed in the lesson enactment emerging from a single or two episodes from the lesson plans. The first lesson was centered on teaching the conditions of Chemical Equilibrium, used to explain this aspect.

Noma's lesson 1: Conditions for Chemical Equilibrium

Even though the episodes were identified from different sections within the lesson plan, only one section allowed for a detailed explanation of how the entire lesson concepts, including the conceptual teaching strategy, would be sequenced. It is in this section that the PPSTs could expand on how they wished to teach the two key concepts, namely (i) the conditions for Chemical Equilibrium and (ii) the factors that affect Chemical Equilibrium.

As stated above, one of the highlights of the observed lessons is that they developed into clusters of TSPCK episodes, expanding from single episodes identified from the lesson plans. One sophisticated TSPCK episode was identified from Noma's lesson plan on how she would teach the conditions for Chemical Equilibrium. In her teaching of this key concept observed during the first lesson 1, six episodes were identified. They constituted two sophisticated episodes, 3 proficient episodes and 1 basic episode. Figure 6.7 displays an excerpt from Noma's lesson plan and a pictorial display of TSPCK maps identified during the lesson enactment.

Looking into the TSPCK maps from Noma's observed lesson below, it can be deduced that the frequency at which some TSPCK components are used is higher, compared to others. The component of representation, for example, appears to be used more than other components in the interactions made. It is followed by the learners' prior knowledge, with aspects of curriculum saliency seeing the least interactions. Also, observable are the two-way TSPCK component

interactions that are central in the episode formations. The two-way component interaction that is common across the TSPCK maps is the one between LPK and R, a total of 4 interplays. Other dominant interplays are seen between R and WD versus LPK and WD, with 3 observed interactions.

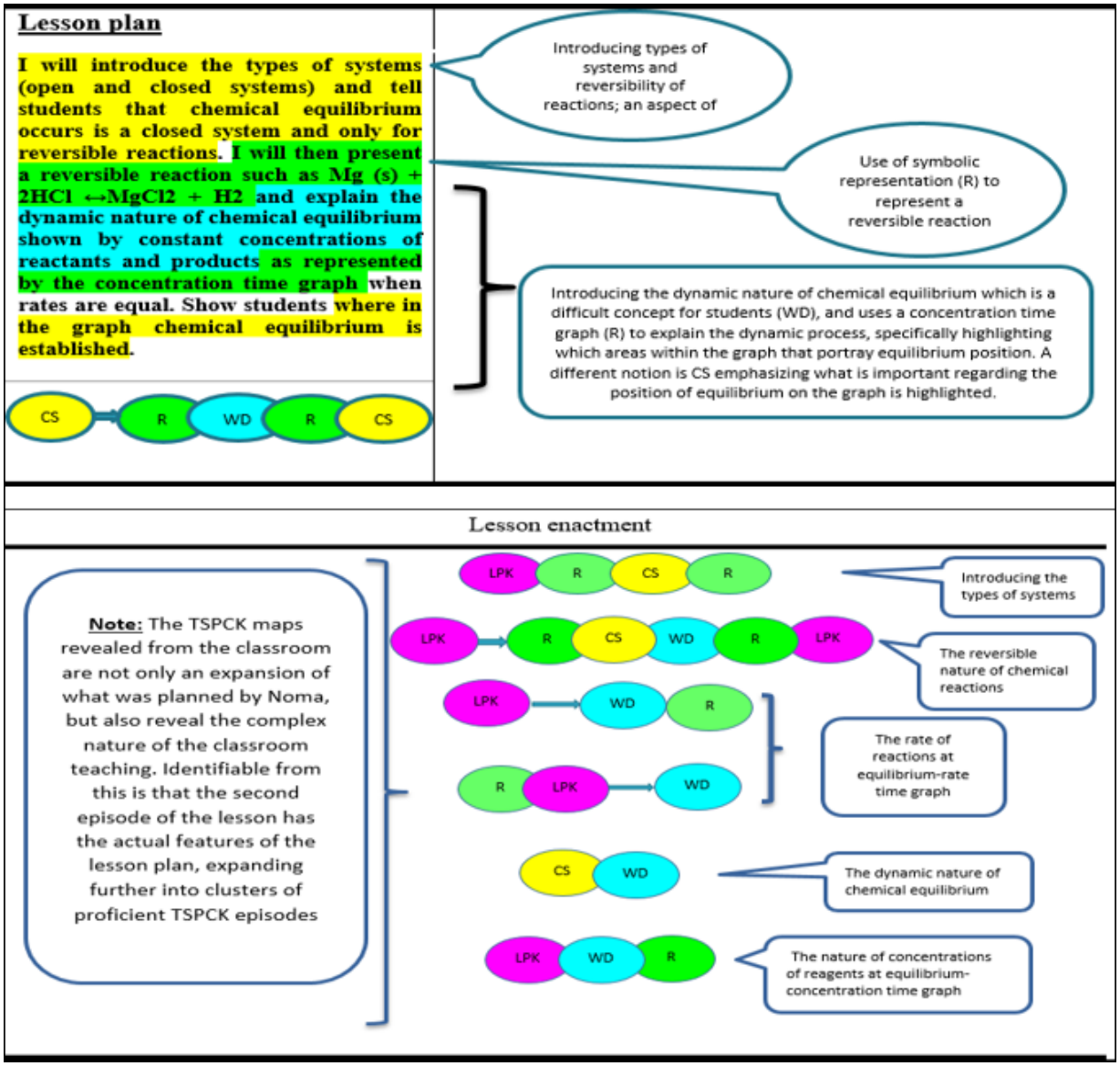


Figure 6. 7: An overview of Noma's lesson plan versus her enacted TSPCK episodes for the first lesson

What Noma provided as a single episode describing how the concepts will be discussed spiraled into episodes' clusters structured in the same sequence from the lesson plan. Thus, the sequence in which TSPCK components interact within the planned lesson episode emulated that of the emergent episodes in the lesson. For example, what was identified from the lesson plan as a single

TSPCK component and part of the identified episode, emerged in the lesson as a complete TSPCK episode, a 4-component episode introducing the concept.

The case of Lerato

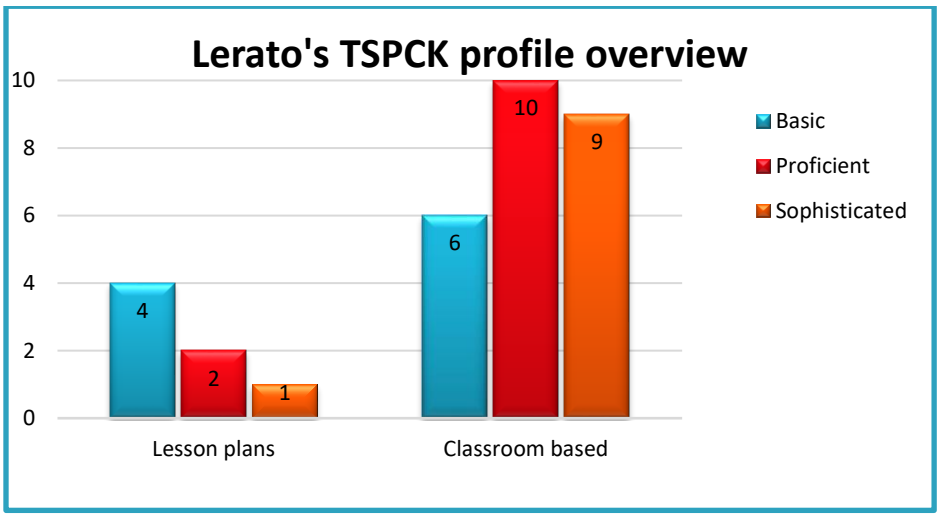


Figure 6. 8: An overview of Lerato's TSPCK; lesson plans versus lesson enactment

Lerato' lesson plan displayed a total of sevenths episodes, 4 basic episodes, 2 proficient episodes and 1 sophisticated episode. The episodes were extracted from three areas within the lesson plan, from the learner difficult concepts, from the suggested representations and on sequencing and conceptual teaching strategies. The first two basic episodes, WD/R, were based on aspects considered difficult to understand. These included the dynamic nature of Chemical Equilibrium and the concept of reversibility of reactions. Under the representations, two more basic episodes, R/CS and CS/R, were identifiable. One episode was based on pictures or video simulations to illustrate on open and closed systems. The second was based on the use of double arrows to represent reversible reactions. The remaining episodes identified from the sequencing and conceptual teaching strategies section constituted 2 proficient episodes R/LPK-CS and CS/R-R and 1 sophisticated episode, CS/R-LPK/WD/R.

The enacted lessons portrayed a total of 25 episodes. These included 6 basic episodes, 10 that are at a proficient level and 9 sophisticated episodes. The excerpt below presents a lesson plan extract by Lerato on the reversibility of chemical reactions, versus the lesson enacted.

Lesson plan:	Lesson 4: 15-21mins: *Open and closed systems*
Using a picture of an open pot versus a closed pot; Ask/discuss with the class about what they think it is and from the responses add, and explain and/or correct if necessary learners' identified differences in open versus closed pot. Conclude on slide the important properties of open and closed system. Show a picture of a slightly open pot to reinforce the point and check understanding. **Qualitative in-depth analysis:** Wishes to display a picture of an open and a closed pot to the class (R) and ask them to differentiate between the two (LPK) and then emphasize on the differences between the two types of systems (CS). This is a three component TSPCK episodes as displayed on the TSPCK map below. **A proficient TSPCK episode: R/LPK-CS**  	**Lerato:** Ok, maybe we should start here. So I want you guys to in your pairs right? I want you guys to talk about, to discuss two things right. What happens and what is the difference between you boiling water when there is a lit, and you boiling water when there is no lit? So you put a pot on the stove, you pour water, then you boil it, you don't put a lid on top. Then the second situation, you put a lid on top and let's assume that the lit is air tight. It doesn't do funny things. So you even extra seal it, you extra seal. So discuss amongst yourselves for five minutes as I prepare this then we'll talk. ... Right we are back, so what did you guys at the back discuss, what did you find? One std: Ok, eh, when there is no lit eh... **Lerato:** When there is no lit? **Same std:** Yes. When there is no lit, we lose water... **Lerato:** We lose water right? **Same std:** The water will evaporate **Lerato:** yes... (writes it on the board) **Same std:** Eh, when there is a lit, it will not evaporate... **Lerato:** If there is a lit? **Same std:** yes **Lerato:** If we have a system that is open, what happens? **One std:** We lose **Lerato:** We will lose right? So in general chemistry language we say we lose mass right? So we are gonna loose of whatever we have in there right? Eh, it doesn't necessarily have to be lost to; it doesn't necessarily have to be lost through evaporation, by evaporation or anything like that. but because of what we saw that there are constant collisions that are happening right, if you have the liquid, then the temperature outside also has, plays a role in evaporating some of it out. If it is a gas, then obviously it is gonna escape right? So we know, in an open system, we are gonna lose staff. This means we can never really achieve that whole converting back that he was talking about. Which is very important to the concept of chemical equilibrium? Secondly, in a closed system, we are not losing anything right. So which means, you keep getting this whole process of your staff are turning back into other staff, and then staff is turning back to other staff right? This is actually very powerful because it means if you think about it, if we are in a closed system our reaction never really stops. It never stops. Even if looks like it stopped, it doesn't stop. Which is quite interesting because you know, generally you will see a beaker and say, ah no, that thing was blue, now it's pink. So it stopped this thing right. But because of what we know from collision theory right, the collisions become less and less likely to happen. So which means your products that are forming are not big enough to show that huge change for you to say, ah no there is some bluish color there...So remember we are talking about particles here. Particles are super small, very small. So you can't even say, ah, no three of them here, we have got 10 there...you know. And that is what is important. It's that, because that happens at a microscopic level, you can't see that observable change. You can't see that it is happening but it is happening right? Because we know that in a closed system, right, that there is this continuous rearrangement back and forth with reactants forming products and products back to reactants. It is however relevant to note that when we are dealing with water, water is not actually, there is no chemical reaction when dealing with water. Water is still water. It is just water in another phase. You know this, it is still water. When we look at closely, specifically other chemical reactions that are actually having a chemical reaction right. So this is not a chemical reaction. It is just a physical reaction. But it is important that we use it to sort of understand and get our heads around what exactly happens in a closed system and sort of have a basic idea of what happens in an open system.

Qualitative in-depth analysis of the enacted lesson:

The segment begins with a scenario of boiling water in a closed versus an open pot (R) which learners are to discuss in their groups and give feedback (LPK). Lerato goes on to introduce learners to the types of systems open and closed, and their characteristics in terms of loss of mass by open systems, and the opposite for closed systems (CS). Further emphasis by Lerato pointed out the continuous nature of reactions in the closed systems that never end, where reactants rearrange forming products, whilst at the same time products react back into reactants (WD). His explanation also highlighted that the reversible nature of the reactions can only be seen at a microscopic level (R).

Four components are interactively linked in this episode as displayed on the TSPCK map below.

A Sophisticated TSPCK episode: R/LPK-CS/WD/R



Figure 6. 9: Lerato's lesson plan extract and enactment on types of systems

The excerpts above detail how Lerato had planned to teach about the types of systems and how that evolved in the lesson. A 3-components proficient episode was portrayed by the lesson plan, R/LPK-CS, but a more complex teaching segment emerged in his teaching. The actual enactment gave rise to a more complex, sophisticated episode with four different components evidently interacting and one repeating distinguishably, R/LPK-CS/WD/R. However, the enacted lesson (the first 3 components in the episode) is the exact replica of the lesson plan episode, with an expansion of two more components. An extract below was taken from Lerato's lesson plan where he explained how he would teach the conditions necessary for Chemical Equilibrium.

Presented below are episodes extracted from Lerato's lesson plan and teaching on conditions for Chemical Equilibrium. From the enacted TSPCK maps, it can be noted that Lerato's lesson episodes are dominated by the use of the CS component in the interplays. The CS component together with R, are observed in every episode presented in the TSPCK maps except for one last episode which does not have R. The central two-way TSPCK component interactions are CS-R, LPK-CS and CS-WD. The less common interactions are LPK-WD, LPK-R and R-WD.

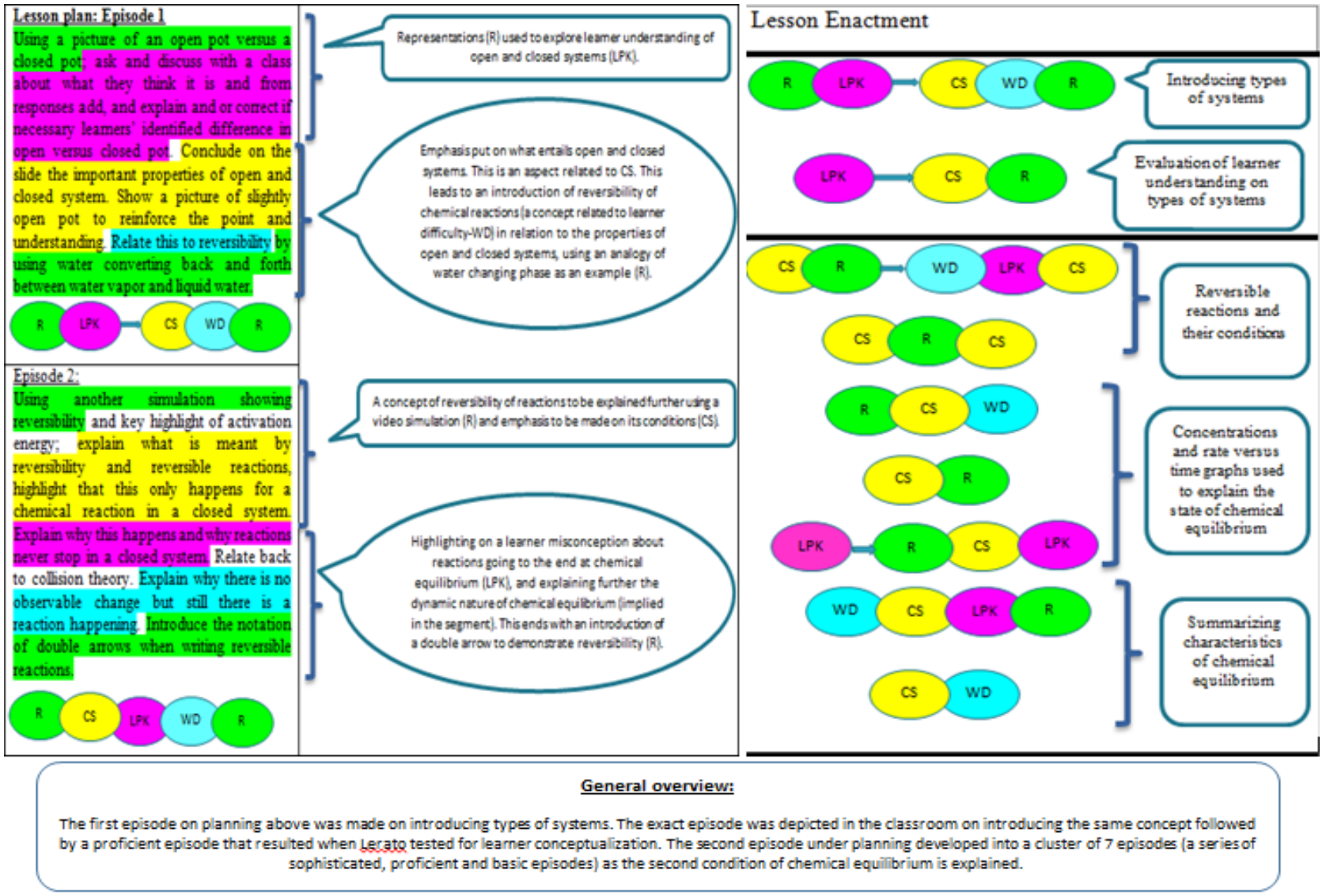


Figure 6. 10: Lerato's lesson 1 on conditions for Chemical Equilibrium

The lesson plan excerpt above shows that two TSPCK episodes were identified in Lerato's lesson plan. Thirteen TSPCK episodes however emerged and were identified in his teaching. These comprised 5 sophisticated TSPCK episodes, 6 proficient and 2 categorized at a basic level. Evident from the lesson enactment section above is that, although generalized in just two episodes in the lesson plan, four sub-concepts are discussed; they include, *types of systems, reversibility of reactions, rates of reactions and concentrations of reactants and products at equilibrium and the use of graphs to explain Chemical Equilibrium*. It can also be noted that each of those sub-divisions is also made up of and explained in more than one TSPCK episode, thus contributing to the increased number of TSPCK episodes in the actual enactment of the lesson.

A lesson by Sara

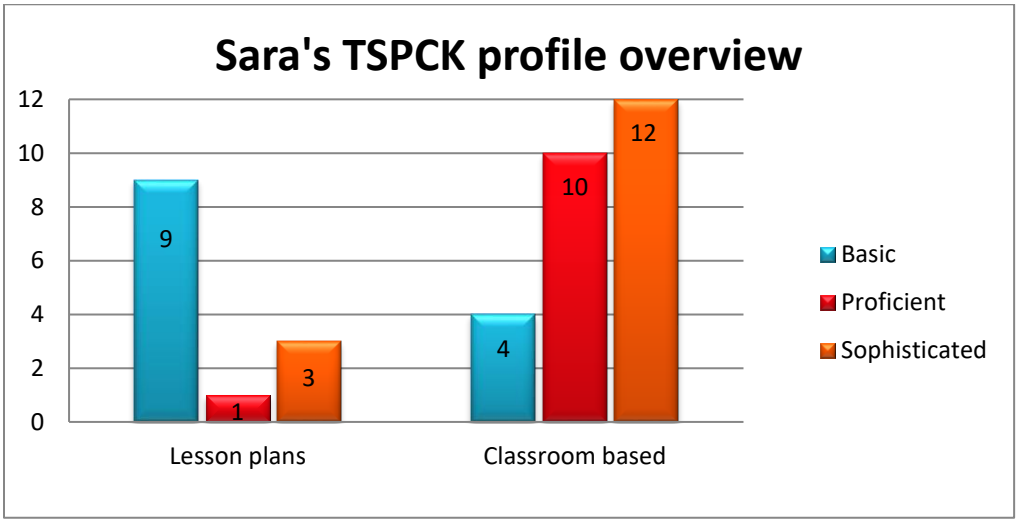


Figure 6. 11: An overview of Sara's TSPCK; lesson plans versus lesson enactment

Thirteen episodes were identified from Sara's lesson plan, 9 basic TSPCK episodes, 1 that is proficient and 3 categorized as sophisticated. Six of the episodes emerged under the sequencing of the lesson. They included 4 basic TSPCK episodes and 2 sophisticated episodes. Four episodes made up of 3 basic and 1 proficient TSPCK episodes emerged under summarizing important content knowledge. The remaining 3 episodes emerged under the use of representations; two of those were basic and one was proficient.

In the actual classroom teaching, the number of basic episodes reduced to 4, whilst the number of proficient and sophisticated episodes increased retrospectively. Sara's lesson was therefore dominated by sophisticated TSPCK episodes as opposed to her lesson plan which was

predominantly characterized by basic TSPCK episodes. Displayed below are the extracts from Sara's lesson plan and the observed lesson qualitative analysis excerpt on the factors that affect Chemical Equilibrium (refer to episode 21 on Table 6.5 for complete overview of the concept taught).

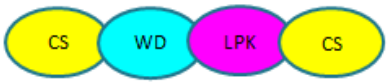
Lesson plan:	**Lesson enactment:** *Introducing factors that affect chemical equilibrium*
Category 2: *conceptual teaching strategy* We then highlight that we had established that at equilibrium the temperature, pressure and concentrations of reactions remain constant. We now want to know what would happen if these three are changed or do not remain constant. Introduce Le Chateliers Principle and how it governs a change in the three factors affecting chemical equilibrium	**Refer to Lesson 21: 89-96mins table 6.3 above** **Qualitative in-depth analysis:** This teaching segment introduces the factors that affect chemical equilibrium; change in pressure, temperature and concentration. These are key concepts crucial to the understanding of the topic (CS). The effect of the disturbance is explained through an introduction of a Le Chatelier's Principle where a system always acts to counteract the effect of a disturbance. This aspect of the effect of a disturbance is not an easy concept for the students to comprehend (WD). This is seen in the emphasis that the teacher does, repeating the principle multiple times. Sara then reminded students that the effect of change in concentrations can only be considered for aqueous solutions, while pressure changes are applicable when dealing with gaseous molecules. This is related to what students should have learned in earlier grades, hence it is an aspect related to learner prior knowledge (LPK). She then provides learners with sequential steps to follow in deciding how a disturbance will affect an equilibrium position, bringing forth a different aspect of curriculum saliency (CS). The episode shows an interaction between three different TSPCK components in an explanation with as aspect of curriculum saliency repeating. The interactions are demonstrated in the TSPCK map below. **An interwoven sophisticated TSPCK episode: CS/WD/LPK/CS**
Qualitative in-depth analysis: In this second category of the lesson plan, Sara also talked about how she wished to introduce the concept on factors affecting chemical equilibrium. She plans to do this by referring students back to the fact that the 3 factors concentration, pressure and temperature had to remain unchanged for chemical equilibrium to be achieved as per the earlier discussions on the topic. This she would follow by introducing the Le Chatelier's principle as a concept that assists with deciding on the effect of a disturbance on chemical equilibrium. This is all an aspect of curricular saliency (CS). **Only one TSPCK component is evident in this segment, hence this is not a TSPCK episode.**	

Figure 6. 12: Sara's lesson plan extract and enactment introducing factors that affect an equilibrium state

As alluded to earlier, the quality of PPST's TSPCK and teaching is not determined only by the presence of TSPCK components in a teaching segment but also by their ability to interactively use those components coherently in their explanations. Even though Sara's lesson plan did not exhibit any interplay of TSPCK components, as displayed in the above extract, her lesson enactment portrayed an episode displaying an interplay of four TSPCK components on introducing the same concept, **CS/WD/LPK/CS.**

The excerpts below portray the episodes extracted from Sara's lesson plan and teaching on conditions for Chemical Equilibrium. Two TSPCK components, LPK and R, are central to the interactions. Accordingly, these are the two-way TSPCK component interactions placed in the order of decrease in frequency LPK-R, CS-R, WD-LPK, WD-R, CS-LPK and CS-WD.

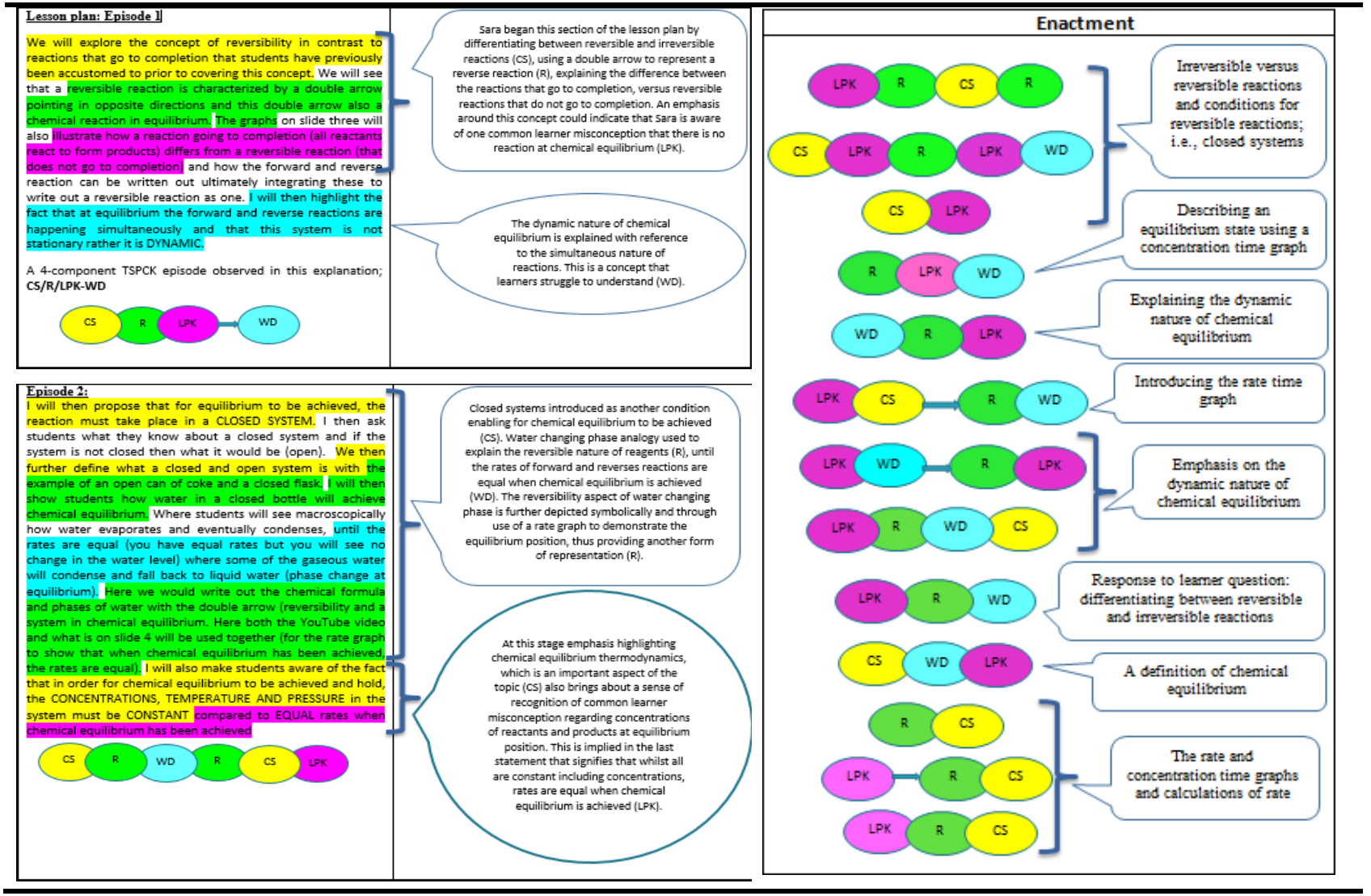


Figure 6. 13: Sara's lesson 1 on conditions for chemical equilibrium

The first sophisticated TSPCK episode from the lesson plan was aimed at differentiating between reversible and irreversible reactions. This episode propagated into a cluster of 5 TSPCK components during the enacted lesson. The second episode identified from the lesson plan had elements within it that were aimed at addressing some important concepts which were not explicitly mentioned in the teaching of the content. The episode emerged into a cluster of 3 sophisticated TSPCK episodes and 1 proficient episode. The last four TSPCK episodes were not on the lesson plan but were used to put more emphasis on the conditions and the state of Chemical Equilibrium, mainly from describing the two graphs- rate and concentration time graphs. It is also important to highlight that 6 more episodes into the second lesson, which are not presented in the above picture, were still based on conditions for Chemical Equilibrium. These are LPK/R/CS/LPK, LPK/WD, LPK-R/WD, LPK-R/CS, LPK-R/CTS/CS, LPK-R/WD/CS. These are the episodes through which Sara tested for learner understanding of important concepts learned from the previous lesson.

6.3.3. Lesson episodes triggered by learners' questions or responses to the questions asked by the PPSTs

Alluded to earlier in this chapter is that there are numerous factors that can influence instructional practices, triggering a teacher to deviate slightly from their original plan (Gess-Newsome, 2015).In this case, the questions asked by the learners, some of which were caused by their confusion, led to an increase in the number of teaching episodes identified in the PPSTs' enacted lessons when teaching Chemical Equilibrium. Three episodes from Lerato's lesson were prompted by the learners' questions. These are episodes 10, 15 and 21; LPK-R/CS/LPK, LPK-CS/WD/R/LPK and LPK-CS/R, respectively. Four of Noma's episodes were prompted by the learners' confusion observed in their responses to the questions asked, whilst 1 was initiated by a question asked by one of the learners. These are episodes 4 (WD/LPK/R), episode 5 (R/LPK-WD), episode 8 (CS/LPK-CS/WD), episode 9 (LPK-R/WD), and episode 14 (LPK-CS/R). On the other hand, 5 of Sara's episodes were identified as linked to the questions asked by the learners, episode 8 (LPK-WD-R/LPK), episode 10 (LPK/R/WD), episode 13 (LPK-R/CS), episode 14 (LPK/R/CS) and episode 18 (LPK-R/CS) whilst the other 5, episode 15 (LPK/R/CS/LPK), episode 16 (LPK/WD), episode 17 (LPK-R/WD), episode 19 (LPK-R-CTS/CS) and episode 20 (LPK-R/WD/CS), were linked to the responses given by the learners.

What can be distinguished as common across all these episodes is the number of components interacted when the questions or confusions identified were addressed by each of the PSTs. The episodes were mainly at a proficient level, displaying the interplay of three components for most of the given responses. Another distinguishable feature is that almost all the episodes above include within them a component of representations (R) interactively used with other components in response to the learners 'concerns. This in accordance with an argument by Mitchell et al. (2014) that it is through the use of representations that conceptual understanding is improved by assisting the learners to visually see and make sense of the subject matter.

6.3.4. The teaching segments entailing difficult concepts and or common learner misconceptions mainly proficient and sophisticated

The difficult/abstract nature of Chemical Equilibrium has been declared in the literature (Mavhunga & Rollnick 2013; Pekmez, 2010). A number of concepts were listed on the PPSTs' lesson plans as contributing to the difficulty of the topic. These included: (*a) the terminology used such as the difference between constant (unchanging) and equal (the same), (b) relating the concentration vs. time graph to the rate vs. time graph (the rate graph is a 'derivative' of the concentration-time graph), (c) the dynamic nature of Chemical Equilibrium, (d) the idea of forward and reverse reactions taking place at equal rates when equilibrium has been achieved and not disturbed, (e) how pressure affects Chemical Equilibrium (be it an increase or a decrease in pressure), including (f) the reversibility of chemical reactions.*

Several episodes per PPST were seen to address some of these difficulties, and almost all those episodes were of high quality, ranging between proficient and sophisticated levels. It can be deduced from the PPSTs' lesson 1 TSPCK episode maps presented in the above sections that episodes that include a WD component are at interplay with two or more other TSPCK components. One of the episodes that introduced the reversible nature of reactions by Noma is episode number 3; a sophisticated episode with an interaction between 4 different components where one TSPCK component was repeating (**LPK-R/WD/CS/R/LPK)**. When asked why it was important to understand this aspect, Noma responded.

> *"When they are introduced to reactions, students deal with one-way kind of reactions. That is, those reactions that go to completion, with a single arrow like A Plus B forming C. So, the arrow faces C to show that it is a one-way reaction. When*

introducingChemical Equilibrium, we deal with reactions that reverse. We focus on reversible reactions, right. But students have a difficulty removing the idea that they already have about that single headed arrow. So, explaining this to them is very important. This is why I used the concept of water evaporating and changing back to liquid in a closed container to help them see how reactions can reverse".

In her own teaching, Sara also used an analogy of water changing phase to explain the concept of reversibility of reactions leading to dynamicChemical Equilibrium. When asked why the use of the analogy was important, she argued that learners can easily relate with the phase change process because of their everyday interaction with the processes. She pointed out further that because they could see in the demonstration that not all liquid water evaporated before condensation starts; this enhances their understanding of the simultaneous nature of both forward and reverse reactions that the forward reaction does not have to end before the reverse reaction begins. The explanation provided herein could be aligned with what studies by Rollnick and Mavhunga (2014) and Malcolm (2018) attest to, namely that at a basis of every conceptual teaching strategy lies the two components of TSPCK, the knowledge of WD and LPK components specific to the concept being taught.

The PSTs also identified and listed some of the common learner misconceptions around Chemical Equilibrium in their lesson plans most of which were addressed in the explanations given by the PPSTs in their teaching. The following misconceptions were observed in the PPSTs' teaching.

i) At equilibrium there is no reaction taking place as no reaction is seen taking place at a macroscopic level.

ii) Before chemical equilibrium is achieved the forward reaction must go to completion and then the reverse reaction will start until chemical equilibrium is achieved.

iii) The concentrations of the reactants and the products must be equal in order to achieve chemical equilibrium.

Also related to the response given by Sara in the paragraph above, in his teaching, Lerato's response in one of his episodes emphasized an aspect that learners find difficult. The difficulty of this concept also leads to a misconception concerning reversibility of chemical reactions. In that excerpt, episode 6 (**CS/R-WD/LPK/CS),** Lerato emphasized the continuous nature of the reaction where the reactants keep forming products and at the same time products react back into reactants

(WD). He went further to explain to the learners that the reverse reaction does not only start after all the reactants have formed into products. This is a common learner misconception (LPK), as presented in the list above.

It is also important to note that those concepts identified as difficult by the PPSTs as well as the listed common learner misconceptions were amongst those that were discussed in the intervention and discussed in more detail in chapter 4.

6.5. Summary

The discussions in this chapter aimed at explaining the quality of the PPSTs' enacted TSPCK. The purpose was to track how their pTSPCK, which was acquired through a module that aimed at developing their knowledge for planning to teach Chemical Equilibrium (cTSPCK for teaching Chemical Equilibrium), translated into TSPCK in action.

The PPSTs lesson profiles displayed four similar trends that provided an insight into the PPSTs personal TSPCK in the context of teaching Chemical Equilibrium. These are: (i) first, the identified TSPCK episodes and component interactions are complex and idiosyncratic; (ii) second, the higher number and more complex TSPCK episodes are found in lesson enactment than in the PPSTs' lesson plans; (iii) third, some lesson episodes were not planned but prompted by the learners' questions or responses to the questions asked by the PPSTs;(iv) fourth, the episodes that explained difficult concepts or addressed common learner misconceptions were mostly of proficient and sophisticated nature.

All the three PPSTs' lessons portrayed a high quality of TSPCK episodes, where the explanations given provided a comprehensive detail that the learners could efficiently conceptualize. As alluded to earlier, the quality of PCK in association TSPCK, is determined by the coherent interplay of multiple components which can then be used as evidence of the teacher's TSPCK development (Mavhunga, 2018; Park & Chen, 2012). The knowledge of individual TSPCK components and the nature of the interactions between content knowledge TSPCK components seen in their lessons were at the heart of the intervention discussions. This is in accordance with Mavhunga and Rollnick (2013) that, the use of the TSPCK framework of content knowledge transformation offers an opportunity for one to transform the content into a form that the learners can efficiently understand. The results obtained in chapter 5 revealed a development in the shifts in the quality of

the PPSTs personal TSPCK for planning (plTSPCK) to teach after the intervention. With the PPSTs lessons predominantly characterized by TSPCK episodes of high quality (proficient and sophisticated episodes), this could be viewed as signaling the impact of the intervention on their teaching of Chemical Equilibrium. Although not a clear link can be made between the intervention and what transpired in the PPSTs' lessons, what is evident is that: (i) their plTSPCK improved after the intervention and (ii) that their lessons exhibited TSPCK episodes of high quality because of their interactive use of 3 and more components in their explanations, which explains the nature of their eTSPCK.

As alluded to in chapter 5, the impact of exposing the PPSTs to the intervention that uses a TSPCK framework has been covered by multiple researchers. What was common across those different studies is that the PPSTs experienced a gain in their plTSPCK scores after the intervention (Mavhunga, 2019; Mavhunga & Rollnick, 2013). Although those studies were mainly focused on B.Ed. PSTs who had an exposure to the construct for an extended period of 4-years, it is important to note that the PPSTs' plTSPCK whose exposure to the cTSPCK was limited to 6-weeks within their 1-year programme also improved after the intervention. This advocates for the potential of the intervention in developing a teacher's knowledge for teaching a topic, PPSTs in this case.

The next chapter, chapter 7, presents the results on learner performances in the learner-achievement tests on Chemical Equilibrium.

CHAPTER 7

MEASURING THE IMPACT OF PPSTs' TEACHING ON LEARNERS' PERFORMANCE IN CHEMICAL EQUILIBRIUM

The previous chapter explained the PPSTs' eTSPCK on their teaching of Chemical Equilibrium, a topic of intervention. This was done to examine how their planned TSPCK translates into classroom enactment. Overall, the findings portrayed a high level and quality of TSPCK in the PPSTs teachings, with their eTSPCK categorized mostly at proficient and sophisticated levels. One of the most important and key features of quality teaching, which is determined by looking at the teachers' eTSPCK, is its ability to positively impact on learner outcomes. It is for this reason that this chapter examines the impact of the observed PPSTs' teaching on learner achievement. The pre- and post- learner achievement tests for each PPST's learners is analyzed and compared.

7.0. Introduction

The previous chapter, Chapter 6 examined the PPSTs' TSPCK enacted in the classroom on a topic of Chemical Equilibrium, to understand how their planned TSPCK translated into classroom enactment. This chapter examines the learners' performance in Chemical Equilibrium concepts after the PPSTs' teachings. The way the teachers teach has been recognized to make an impact on the learners' conceptual knowledge and understanding which is reflected in how they perform in class (Kind, 2018; Aydin & Boz, 2013). The learner outcomes are accordingly considered a way of determining the quality and effectiveness of an instruction (Carlson & Daehler, 2019). This chapter analyzed the pre- and post-learner achievement tests on Chemical Equilibrium. The pre- and post-tests were administered before and after the PPSTs' teaching, respectively.

7.1. Brief Summary on Methodology

As explained in Chapter 3, the study employed a mixed method design in analyzing for shifts in learner achievements. A total of 43 Grade 12 Physical Science learners, divided into three classes of 15, 14 and 14 respectively were taught by the three PPSTs. The learners were from three Secondary Schools in Johannesburg area which fall in the same category of South African schools. The category is called Ex Model C. This category is distinguished from other categories in that these schools were previously classified as white schools during the Apartheid regime (Soudien & Sayed, 2003). Table 7.1 presents summarized information about the participants.

Table 7. 1: Important information about the participant PPSTs and their learners

Pre-service teacher	Content discussed in Chemical Equilibrium lessons	Learners per PPST's class			
		Grade	Male	Female	Total
Noma	1. Conditions for Chemical Equilibrium. 2. Factors affecting Chemical Equilibrium.	12	7 (47%)	8 (53%)	15
Lerato	1. Conditions for Chemical Equilibrium. 2. Factors affecting Chemical Equilibrium.	12	7 (50%)	7 (50%)	14
Sara	1. Conditions for Chemical Equilibrium. 2. Factors affecting Chemical Equilibrium.	12	9 (64%)	5 (36%)	14

Note: Pseudonyms have been used to protect the identity of the learners

All the 3 PPSTs taught on the same two concepts of Chemical Equilibrium listed on Table 7.1 spread between two lessons of 60 minutes each. Noma's lesson had a total of 15 learners made up of 7 male and 8 female participant learners. Lerato's lesson had an equal number of male and female participant learners, making a total of 14 learners in the class. Sara, on the other hand, had a class of 14 learners that was male dominated (9) and the other 5 learners were female. Two of the male learners from Sara's class did not write the pre-test, hence were not included in the analysis. This reduced her class size to a total of 12 learners: 7 males and 5 female learners.

7.1.1. The structure of the learners' achievement tests

The main purpose of giving the achievement tests was to measure the learners' performance in Chemical Equilibrium concepts in order to observe a change, if any, in their performance after the PPSTs' teaching of the topic. The test consisted of 12 items related to (i) conditions leading to Chemical Equilibrium and (ii) Factors that affect the state of Chemical Equilibrium. These are the two Big Ideas in Chemical Equilibrium. Organizing the content of a topic through Big Ideas is an idea adopted from Loughran et al. (2004), where Big Ideas refer to meaningful statements that give the correct understanding of the key concepts of the topic. The exact test which the learners took between 20-30 minutes to complete was written as both a pre- and a post-test. The learners had not learned about the topic of Chemical Equilibrium before the PPSTs' teachings. Table 7.2 shows the kind of questions asked. The actual test is attached as Appendix D. It is important to note that two items (1 and 10) were found to be similar hence item 10 was removed from the list and not used in the analysis.

Table 7. 2: Description of the content covered in the test

Test Item	Content Description
Item 1	Rates of reactions at Chemical Equilibrium
Item 2	The effect of increase in the yield of products for exothermic reactions
Item 3	Concentration of products at Chemical Equilibrium
Item 4	Effects of a disturbance at Chemical Equilibrium
Item 5	Drawing a concentration versus time graph to demonstrate Chemical Equilibrium
Item 6	Explaining what an open system is
Item 7	Explaining what a closed system is
Item 8	Explaining reversible reactions
Item 9	Explaining dynamic equilibrium
Item 10	Rate of forward and reverse reactions at Chemical Equilibrium
Item 11	Effects of increasing the concentration of product to a reaction that has reached Equilibrium
Item 12	Explaining the response to Item 11 using the Le Chatelier's principle

7.1.2. Analysis of the learners' performance tests

First, a marking memorandum of correct answers was developed by the researcher and its correctness checked by two independent raters who are chemistry education specialists with an experience of 7 and 25 years in science teacher education, respectively. The content test questions consist of one correct answer. Each item was scored as 0 or 1 for the wrong and correct responses respectively (see Appendix D). After marking all the tests, one additional chemistry specialist validated all the marked scripts to confirm the accuracy of the content and consistency of the marking. The discrepancies with the marking were discussed until a consensus was reached. The raw scores obtained from the marked tests were quantitatively analyzed using the Rasch Winstep Software. As explained in Chapter 3, the Rasch model converts the raw scores into probability measures on an equal interval scale (Boone, Staver & Yale, 2014). The raw scores for each person are converted into linear measures and placed at an equidistant scale (Bond & Fox, 2015). The Rasch ability measures are further subjected to the Wilcoxon Paired Signed Rank test (WPST) for non-parametric data in order to test for the significance difference, if any, between the pre- and post-test performance scores of the learners. This test is considered suitable for use in the analysis of small sized samples; hence it is appropriate in this study.

7.2. Quantitative Findings on Learners' achievement in Chemical Equilibrium

7.2.1 An overview finding of learners' performance (ordinal raw scores)

Presented in this section is an overview of the 3 PPSTs' learners' performance scores from pre- and post-achievement tests on Chemical Equilibrium. The raw learners' scores per test were first converted to percentage scores for normative analysis of the overview picture. Table 7.3 below displays the PPSTs' learners' raw scores from their written pre-and post-tests on Chemical Equilibrium. A more detailed analysis follows immediately.

Table 7. 3: Learners' raw scores on pre-and post-tests displayed

Noma's group			**Lerato's group**			**Sara's group**		
Name of Learner	Pre-test (%)	Post-test (%)	Name of Learner	Pre-test (%)	Post-test (%)	Name of Learner	Pre-test (%)	Post-test (%)
GELO	**0**	**75**	MPHO	**8**	**75**	TATO	**17**	**75**
KEAM	**8**	**83**	SEGO	**8**	**67**	LERA	**25**	**83**
GUBE	**8**	**75**	LIND	**17**	**67**	KAMO	**25**	**83**
PELI	**8**	**67**	SELO	**17**	**75**	BUKA	**33**	**83**
MOLI	**17**	**75**	NALD	**25**	**83**	KEKA	**33**	**75**
MAYO	**17**	**67**	TOKA	**25**	**83**	TEBO	**33**	**67**
BALO	**17**	**58**	DIWE	**25**	**83**	MBIZ	**42**	**83**
SEMA	**25**	**83**	EMAN	**25**	**75**	KALO	**42**	**83**
PALE	**25**	**75**	MELI	**25**	**67**	LESO	**42**	**75**
NOSI	**25**	**75**	SILE	**33**	**75**	MAEK	**58**	**83**
BASI	**25**	**83**	DEKA	**33**	**75**	TEKO	**58**	**75**
MAGI	**33**	**83**	RABO	**33**	**67**	ZIMA	**67**	**75**
FELO	**33**	**83**	TUME	**50**	**83**			
KOLI	**33**	**75**	MANE	**58**	**83**			
SAND	**42**	**65**						
Average scores	**21**	**75**		**27**	**76**		**40**	**78**

The scores in Table 7.3 show a general increase across the board in learner performance for each of the 3 PPSTs' classes. Noma's learners' pre-test scores ranged between 0% and 33%. Only 1 learner from Noma's class scored 42% in the pre-test. Two learners from Lerato's class scored between 50 and 58% in the pre-test whilst the rest of the class (12) scored between 8 and 33%. Sara's class had 3 learners scoring between 58 and 67%, respectively and the remainder (9) scoring between 17 and 42%. The post-tests for all the learners ranged between 67 and 83% except for 1 learner in Noma's class who scored 58%. Inclusively, all the learners experienced an increase in their scores after the PPSTs' teaching.

7.2.2. Quantitative in-depth analysis of the learners' achievement per PPST

As alluded to in the previous chapters, each of the 3 PPSTs were considered a mini case. This section then analyses each PPST participant learners separately to explain their conceptual understanding and performance prior to and after the PPSTs' teaching of Chemical Equilibrium concepts.

THE CASE OF NOMA'S LEARNERS

i. ***A performance analysis of raw scores***

Table 7.4 presents the learners' achievement patterns for Noma's learners in detail. Pseudonyms have been used to protect the identity of the learners as required by the ethics protocol. The gains in achievement were calculated by subtracting the pre-test percentage (%) score from the post-test % score which was obtained after the teaching by Noma. The average scores and their corresponding percentages are presented in the last row of the Table.

Table 7. 4: Learners' content knowledge gains on chemical equilibrium concepts: Noma's class

Learner Code	Raw pre-test score (%)	Raw post-test score (%)	Percentage gain (%)
GELO	0	75	75
KEAM	8	83	75
GUBE	8	75	67
PELI	8	67	58
MOLI	17	75	58
SEMA	25	83	58
MAYO	17	67	50
PALE	25	75	50
NOSI	25	75	50
BASI	33	83	50
MAGI	33	83	50
FELO	33	83	50
BALO	17	58	42
KOLI	33	75	42
SAND	42	67	25
Average scores	**21**	**75**	**53**

Note: The arrangement of the learners' codes is in descending order of their gains. Pseudonyms have been used for the learners.

It can be observed from Table 7.4 that all the learners scored below 50% in their pre-test, with the scores ranging between 0 % and 42%. The post-test was however a turn around with almost all the learners (93% of the learners) scoring between 67% and 83%. One learner, Balo, scored below

60% in the post-test. Twelve of the 15 learners (80%) had a percentage gain of 50% and above following Noma's teaching. Looking at the last row on Table 7.4; there is an average gain of 53%.

ii. Raw scores converted into Rasch measures

The pre- and post-test raw scores by Noma's learners were then subjected to the Rasch model to produce Rasch measures using the Winstep Rasch Model. The detailed discussions on the rationale for using the Rasch model are provided in Chapter 3 (section 3.7.3). As discussed earlier, Rasch converts non-linear (ordinal) data into linear Rasch measures that can confidently be used to run other statistical measures (Boone *et al.*, 2014). The person Rasch measures are presented in Table 7.5.

Table 7. 5: The person Rasch scores of the pre- and post-achievement test of Noma's learners

Learner code	Pre-learner achievement test			Post-learner achievement test		
	Rasch person measure	*Fit statistics* IN. ZSTD	OUT. ZSTD	Rasch person measure	*Fit statistics* IN. ZSTD	OUT. ZSTD
KEAM	-2.47	-0.35	-0.24	2.65	0.28	-0.04
BASI	0.03	-0.04	-0.27	2.64	-0.36	-0.49
FELO	0.03	-0.04	0.27	2.64	0.65	1.23
SEMA	0.65	1.46	1.13	2.64	0.65	1.23
GUBE	-2.47	-0.35	-0.24	1.73	0.30	-0.13
GELO	-2.47	-0.35	-0.49	1.73	-0.18	-0.11
MOLI	-1.43	-1.35	-0.80	1.73	0.13	1.57
PALE	-0.65	-1.64	-0.60	1.73	-0.38	-0.46
NOSI	-0.65	1.46	1.13	1.73	-0.38	-0.46
SAND	0.69	1.17	1.34	1.12	-1.08	-1.08
MAGI	0.03	-0.85	-0.77	1.12	-0.20	-0.37
MAYO	-1.43	-1.35	-0.80	1.12	0.43	0.06
BALO	-1.43	-1.35	-0.80	0.62	1.08	0.93
PELI	-2.47	0.69	0 .49	0.18	0.39	0.19
KODI	0.03	-1.41	-1.12	-0.24	0.68	0.22
Reliability indices summarized	Rasch mean	-1.11		Rasch mean	1.54	
	Person reliability	0.74		Person reliability	0.77	
	Item reliability	0.77		Item reliability	0.80	
	Infit/Outfit indices	All within +2;-2 range		Infit/Outfit indices	All within +2;-2 range	

Note: The order in which the learners are presented is based on the descending order of Rasch measures in the post-test. The mean for item measure set to zero & Units per Logit=1 for the tests (UIMEAN=0 and USCALE=1)

The first column represents the codes used to identify each participant learner who wrote the tests. The pre- and post-Rasch person measures are presented in columns two and five, respectively. The fit statistical parameters represented by IN. ZSTD and OUT. ZSTD are provided to measure the coherence of the responses of the persons to the level of difficulty of the items in the test.

The Rasch measures displayed in Table 7.5 show a good reliability for both person and item measures in the pre- and post-learner achievement tests. The calculated person reliability for the pre-test was 0.74 with an item reliability of 0.77. For the post-test, the person and item reliability measures were also found acceptable at 0.77 and 0.80, respectively. It can also be observed from Table 7.5 that the infit/outfit statistics has the values falling within the range of +2 to -2 for both pre- and post- test; this is considered fitting and measuring a single construct. This also implies that none of the responses of Noma's learners were significantly problematic as their measures fit within the accepted range. It is also important to note that the post-test person Rasch measures are higher than the pre-test Rasch person measures. Fourteen of Noma's learners have positive Rasch measures. The only exception is learner KODI in the post-test Rasch analysis. He has negative Rasch measures. This differs from the pre-test Rasch person measures where 9 learners had negative Rasch measures while 6 had positive measures. The positive person measure values in the pre-test are all lower than the person measure values in the post-test. The higher Rasch person measures show a positive improvement in the learners' ability to respond to items of different difficulty levels. The high post-test person measure means of 1.54 compared to the lower pre-test person measure mean of -1.11 is indicative of an improvement in the learners' conceptual understanding and performances.

iii. Rank order for Rasch Item measures

The Rasch model also allows for the establishment of the rank order of items by providing one with the order of difficulty of the items. Table 7.6 presents the Rasch item measures in the terms of the rank of their difficulty. The first two columns present the pre-test Rasch item data while columns 3 and 4 show the post-test item data. For both pre-and post-test sections, the items are arranged in the rank order of item difficulties from the Rasch item measures. Thus, the arrangement is in the order of decreasing difficulty of items.

Table 7. 6: Ranked Rasch item measures for Noma's learners' pre-and post-achievement tests

Pre-test		Post-test	
Item	**Item measure**	**Item**	**Item measure**
Item 4	3.28	Item 2	2.02
Item 11	3.28	Item 11	1.08
Item 5	3.28	Item 5	0.38
Item 2	2.03	Item 10	-0.59
Item 6	0.65	Item 4	-0.05
Item 7	0.65	Item 8	-0.05
Item 1	0.65	Item 1	-0.59
Item 10	0.21	Item 3	-0.59
Item 9	0.21	Item 6	-0.59
Item 8	-0.54	Item 7	-0.59
Item 3	-2.02	Item 9	-1.42

Note: The mean for item measure set to zero & Units per Logit=1 for the pre-and post-test (UIMEAN=0 and USCALE=1).

The Rasch measure values represent the extent of difficulty experienced by the participant learners on responding to each item. The highest value of an item measure shows that the item was ranked as more difficult compared to that with a lower value which reveal that the item was easy to answer correctly. A careful look into Item 2, with a post Rasch measure of 2.02 is considered for this group, as the most difficult in this test whilst item 9 with a Rasch measure of -1.42 logits was the easiest to respond to. Most of the items that were ranked as difficult in the pre-test were later ranked as easy in the post-test. This can be seen in the high number of positive Rasch item measures in the pre-test as opposed to the high number of negative Rasch item measure values in the post-test. A decrease in the Rasch measure values from high to low shows an increase in learner conceptual understanding in their post-achievement test which indicates the decrease in the level of difficulty of most items following Noma's teachings. An example of this could be that of item 4 which was ranked as most difficult for the learners in the pre-test with a Rasch measure of 3.28 logits. The same item was ranked at -0.05 logits in the post-test, indicating a change in learner conceptual understanding and performance.

Table 7.7 below presents the rank order of pre-and post-test Rasch measures side-by-side to analyze the similarities and or differences in the ranking of the items before and after the PPST's teachings.

Table 7. 7: Pre and Post-test rank order Rasch measures for the items compared

Learner achievement test	Item 11	Item 5	Item 4	Item 2	Item 6	Item 7	Item 1	Item 10	Item 9	Item 8	Item 3
Pre	3.28	3.28	3.28	2.03	0.65	0.65	0.65	0.21	0.21	-0.54	-2.02
Post	1.08	0.38	-0.05	2.02	-0.59	-0.59	-0.59	-0.59	-1.42	-0.05	-0.59

The items in the pre- and post-achievement tests were similarly ranked as shown in Table 7.7 above. For instance, items that were found to be very difficult for the learners to respond to in the pre-test were similarly found difficult after the PPSTs' teachings. This can be observed in the first four items: 11, 5, 4 and 2, with item difficulties higher than 2 logits. Three of these items, 11,4 and 2, require an understanding of the Le Chatelier's Principle while 5 was on graphical representation of a reaction that has reached Chemical Equilibrium; and the learners did not have knowledge of those concepts prior to Noma's teaching. The four items were still considered as the most difficult in the post-test. Similarly, items that were ranked as easy in the pre-test were also found easy in the post-test. What is evident however is that, although the ranking order of item difficulties is similar in the pre- and post-tests, the post-test Rasch measures are lower compared to the pre-test item measures, suggesting an increase in conceptual understanding.

Figure 7.1 and Figure 7.2 are the pre- and post-achievement test written responses by two learner participants in Noma's class. The responses are used to demonstrate a change in the conceptual understanding of the topic content resulting from Noma's classroom teaching.

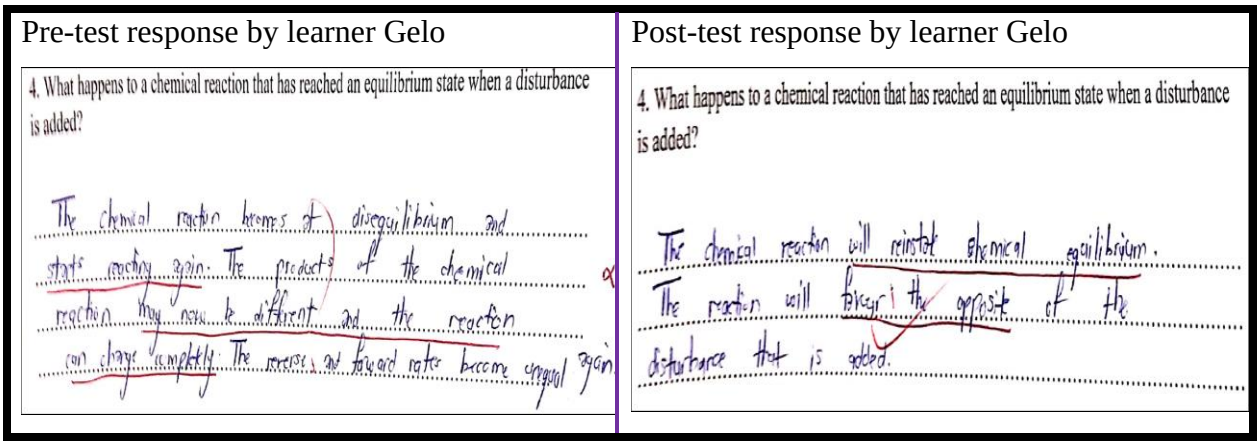


Figure 7. 1: Noma's learner-Gelo's pre and post-test written response for item 4

Item 4 sought the learners' general understanding of how a chemical reaction that has reached a state of chemical equilibrium reacts to any form of disturbance. In order for the learners to answer

the question, they needed to understand the Le Chatelier's Principle. The response for the pre-test shows the lack of understanding of the concept and also brings forth a misconception regarding the reactions that have reached Chemical Equilibrium. This is seen in the first line where the learner argues that the reaction will start again. This response gives the idea that the learner's understanding is that there is no reaction at equilibrium, a common learner misconception for this topic (Pekmez, 2010). The post-test response however revealed an understanding of the concept, where the learner points to the aspect of "favoring a reaction that opposes a disturbance", as the reaction attempts to reduce the stress added to the system.

The second learner's (learner Peli) responses to item 4 are presented in Figure 7.2.

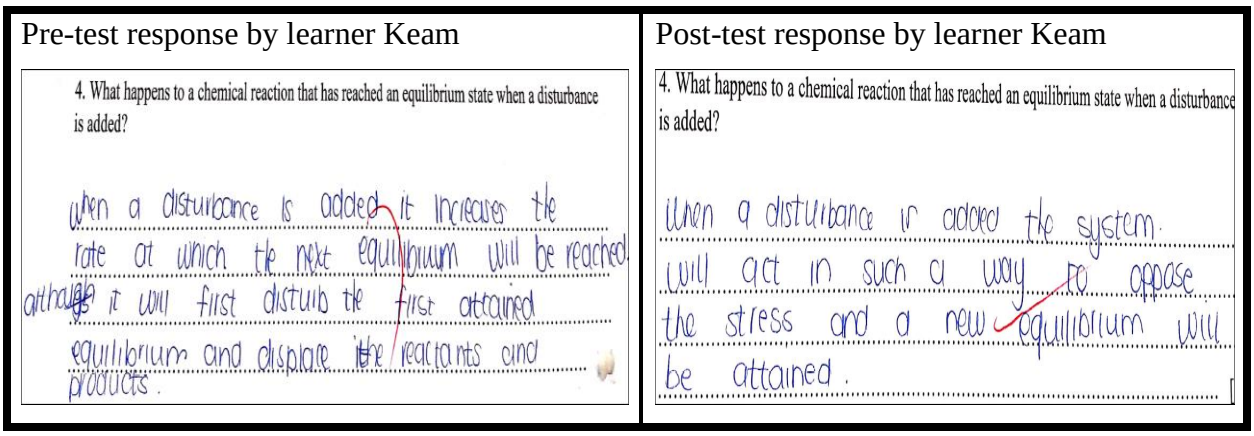


Figure 7. 2: Noma's learner- Peli's pre and post-test written response for item 4

The first response given by learner Peli in the pre-test highlights his lack of understanding of the concept on what the effect of a disturbance would do to a state of Chemical Equilibrium which is governed by the Le Chatelier's principle. For example, learner Peli wrote that the disturbance would cause the next equilibrium to be reached faster. This is false, as the rate will depend on the form of disturbance introduced to the system. Overall, this response shows a lot of confusion on the part of the learner. The post-test response, however, is precise as Peli indicated that the reaction would oppose the added stress/disturbance and re-instate a new equilibrium position. The post-test response by Peli reveals an improved understanding of the concept following the teaching by Noma.

iv. Explaining Noma's learners' person ability

One of the characteristics of the Rasch software is that is it able to measure the person ability in relation to the item difficulty. This allows for one to explain one's ability to respond to the items of different difficulty levels. The map presented in Figure 7.3 includes the pre-and post-test estimates together. The pre-test learner (such as KEAM) code identifiers have four letters. Identifier codes for the post-tests include the letters and numbers together, making a code. These include three-letters-one-number or two-letters-two numbers. For example, the learners coded as KEAM and LERA in the pre-test were coded as KEA1 and LE11 in the post-test, respectively. The numbers represent the order in which the learner codes were entered on the spreadsheet used for Rasch analysis. Thus, the last letters for learners 1 to 9 (e.g., KEA**M**, GUB**E**, etc.) were replaced by those numbers respectively, and the learners from position 10 and higher (e.g., MO**LI**, LE**RA**, etc.) had the last two letters of their names replaced. For example, KEA**1** was the first learner on the list, GUB**2**, was the second learner, MO**10** was the tenth, whilst LE**11** was the 11th learner on the list. This helped me to differentiate between the same person in the pre-test and in the post test.

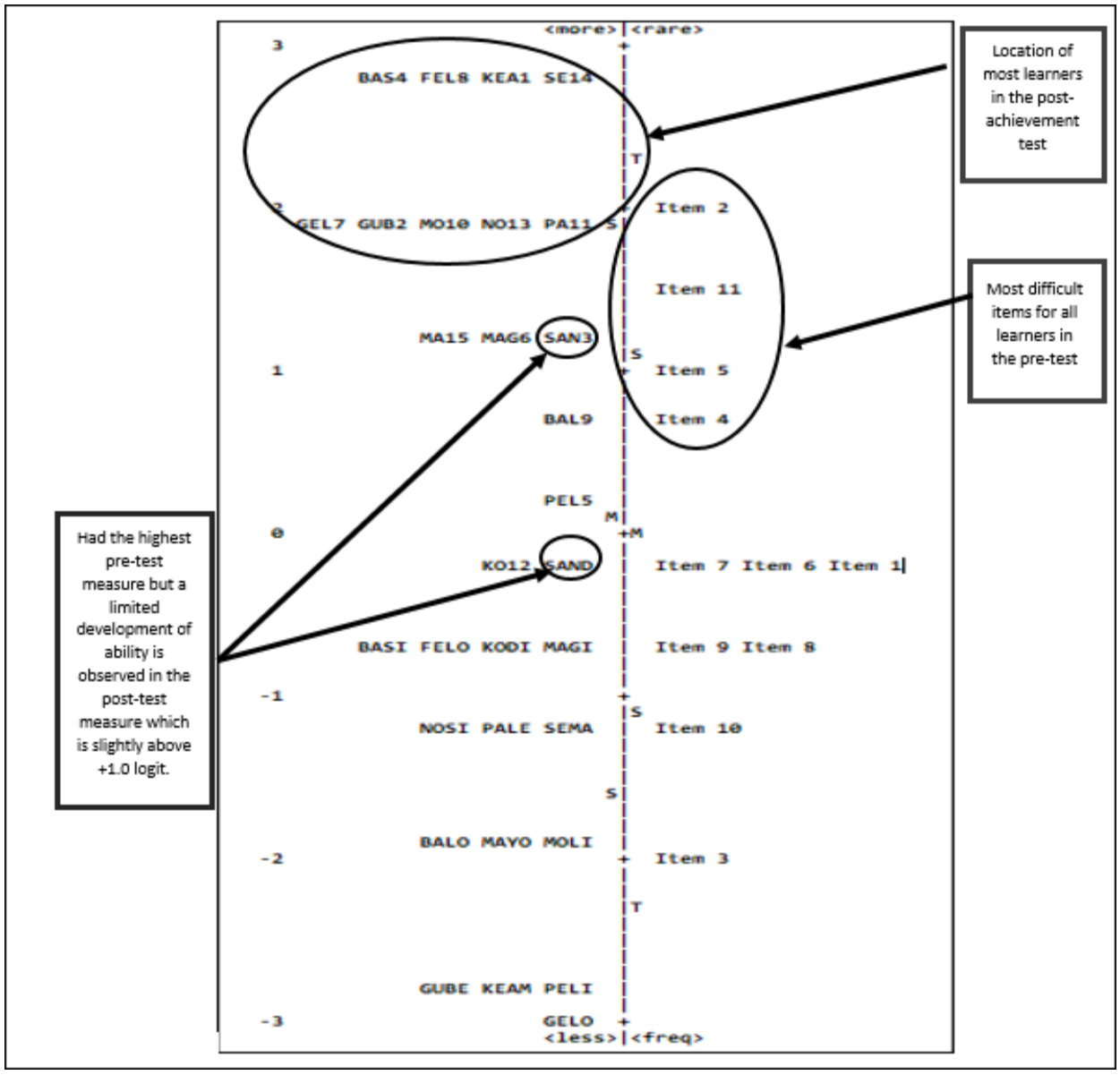


Figure 7. 3: A variable map for Noma's learners pre- and post-achievement test Rasch measures

The results from Figure 7.3 show that in the pre-test the three learners, GUBE, KEAM and PELI, had the lowest person ability which made it difficult for them to respond to any of the items presented in the test. On the other hand, learner SAND is found higher on the map, around 0 logits. The location of SAND on this map suggests that she had a 50% chance of responding correctly to 3 items whose Rasch measures were around a zero-logit margin and 4 others which she could easily respond to. It also shows that she was likely to find about 4 items within the test difficult to respond to.

A shift is, however, observed in the post-test measures of the persons, indicating that their ability to respond to the items had improved. First, all the four learners (GELO, GUBE, KEAM and PELI) that had the lowest person measures of below -3.0 logits, had higher and all the positive person measures in the post-achievement test, now coded as GEL7, GUB2, KEA1 and PEL5. Second, it can be observed that all the learners in Noma's class were located below the zero margins in their pre-test, indicating that they were not able to respond to any items whose Rasch measures were above 0-logits. All the learners' Rasch person measures were found above 0-logits, following Noma's teaching, with more learners Rasch measures towards 2.0-logits and 3.0-logits. This is an indication of an improvement in the learners' person abilities.

v. Comparison of Rasch measures for significance difference

Table 7.8 presents a summary of the anchored Rasch person measures and standard error for the pre- and post-achievement tests. The person measures generated by Rasch were first anchored to produce stacked data. Anchoring requires calibrating the base test and using the item difficulties of the base as reference to calibrate the second test (Linacre, 2012; Mavhunga, 2012). In this case, the pre-test item difficulty measures were anchored, and its item difficulty values used to equate the scale of the post-test. The stacked data was then further analysed for significance difference using the Wilcoxon Paired Signed Rank test (WPRT). Subjecting this data to WPRT enabled for the measurement of the magnitude of the difference between the paired data (Whitley & Ball, 2002).

Table 7. 8: Stacked data- Person measures from anchored pre-and post-test

Learner	Pre-learner achievement test		Post-learner achievement test	
	Rasch measure	Error	Rasch measure	Error
KEAM	-2.75	1.09	4.29	1.14
BASI	-0.72	0.70	4.29	1.14
FELO	-0.72	0.70	4.29	1.14
SEMA	-1.24	0.74	4.29	1.14
GUBE	-2.75	1.09	3.27	0.92
GELO	-2.75	1.09	3.27	0.92
MOLI	-1.85	0.84	3.27	0.92
PALE	-1.24	0.74	3.27	0.92
NOSI	-1.24	0.74	3.27	0.92
SAND	-0.25	0.68	2.50	0.85
MAGI	-0.72	0.70	2.50	0.85
MAYO	-1.85	0.84	2.50	0.85
BALO	-1.85	0.84	1.81	0.81
PELI	-2.75	1.09	1.18	0.79
KODI	-0.72	0.70	0.58	0.78
MEAN	-1.58		2.97	

Figure 7.4 presents the results obtained from the analysis, using the Wilcoxon's Paired Rank Test (WPRT).

Pre-test Person measures	Anchored Post-test person measures	Diff=(Yi-Xi)	Abs(Diff)	Rank	Signed Rank	T	120
-2.75	4.29	7.04	7.04	15	-15	n	15
-0.72	4.29	5.01	5.01	9.5	-9.5	α	0.05
-0.72	4.29	5.01	5.01	9.5	-9.5	Z	3.4
-1.24	4.29	5.53	5.53	12	-12	Reject Null at	0.05
-2.75	3.27	6.02	6.02	13.5	-13.5	p	0.00064
-2.75	3.27	6.02	6.02	13.5	-13.5		
-1.85	3.27	5.12	5.12	11	-11		
-1.24	3.27	4.54	4.54	7.5	-7.5		
-1.24	3.27	4.51	4.51	7.5	-7.5		
-0.25	2.5	2.75	2.75	2	-2		
-0.72	2.5	3.22	3.22	3	-3		
-1.85	2.5	4.35	4.35	6	-6		
-1.85	1.81	3.66	3.66	4	-4		
-2.75	1.18	3.93	3.93	5	-5		
-0.72	0.58	1.3	1.3	1	-1		

Figure 7. 4: Summary for the calculation of significance difference for Noma's learners' performances

The results in Figure 7.4 show the p-value of 0.00064. This value is much smaller than the significance level of 0.05, which indicates that there is a significance difference at 95% (0.05) level between Noma's learners' pre-test and post-test measures. This indicates that Noma's learners'

conceptual understanding improved significantly with 95% confidence following her teaching of chemical equilibrium.

THE CASE OF LERATO'S LEARNERS

(i) A performance analysis of raw scores

Similar to Noma's case, this section analyses the raw scores of Lerato's learners to reveal change in their conceptual performances if any, following Lerato's teaching. Table 7.9 displays the codes that identified Lerato's learners, as shown in column 1, their pre- and post-achievement scores in columns 2 and 3 respectively and the calculated performance gains in column 4. The gains are calculated by subtracting the pre-test score from the post-test score which is obtained after Lerato's teaching.

Table 7. 9: Displaying learners' content knowledge gains on chemical equilibrium concepts: Lerato's class

Learner code	Raw pre-test score (%)	Raw post-test score (%)	Percentage gain (%)
MPHO	8	75	67
SEGO	8	67	58
DIWE	25	83	58
NALD	25	83	58
SELO	17	75	58
TOKA	25	83	58
LIND	17	67	50
EMAN	25	75	50
MELI	25	67	42
SILE	33	75	42
DEKA	33	75	42
RABO	33	67	33
TUME	50	83	33
MANE	58	83	25
Average scores	**27**	**76**	**49**

Table 7.9 shows that none of the learners scored a maximum of 60% in their pre-test. Their scores ranged between 8 % and 58%. On the other hand, all the learners (100%) scored above 60% in their post-test, with their scores ranging between 67% and 83%. The last column shows that all the learners experienced some gains although the overall gain differs from one learner to the other. Eight learners (57%) from Lerato's class had knowledge gains between 50% and 67% on completion of the teaching period whilst 43% had gains ranging between 25 and 42%. Looking at the last row in Table 7.9; there is an average gain of 50% for this group of learners.

(ii) Raw scores converted into Rasch measures

The pre- and post-test raw scores by Lerato's learners were then run through the Rasch model to produce Rasch measures. The person Rasch measures are presented in Table 7.10.

Table 7. 10: The person Rasch scores of the pre- and post-achievement test of Lerato's learners

Learner code	Pre-learner achievement test			Post-learner achievement test		
	Rasch person measure	*Fit statistics*		Rasch person measure	*Fit statistics*	
		IN. ZSTD	OUT. ZSTD		IN. ZSTD	OUT. ZSTD
TOKA	1.23	1.01	0.66	2.40	0.99	0.67
DIWE	0.63	0.51	0.29	2.40	0.87	0.46
NALD	-0.50	1.86	2.05	2.40	-0.78	-0.41
SELO	-0.50	-0.90	-0.73	1.24	0.22	0.33
EMAN	-0.50	0.44	0.04	1.24	-0.34	-0.23
MPHO	-1.13	-0.71	-0.56	1.24	0.62	1.81
SILE	-1.13	-0.71	-0.56	1.24	-0.34	-0.23
TUME	-1.13	1.87	1.20	1.24	-0.71	-0.44
RABO	-1.13	-0.71	-0.56	0.37	0.36	-0.02
SEGO	-1.13	-1.09	-0.76	0.37	-0.95	-0.72
MANE	-1.90	-0.23	-0.15	0.37	0.36	-0.02
DEKA	-1.90	0.28	0.63	0.37	0.36	-0.02
MELI	-3.04	-0.81	-0.57	0.37	-0.95	-0.72
LIND	-3.04	-0.81	-0.57	-0.42	-1.45	-0.89
Reliability indices summarized	Rasch mean	-1.08		Rasch mean	1.06	
	Person reliability	0.60		Person reliability	0.73	
	Item reliability	0.73		Item reliability	0.83	
	Infit/Outfit indices	1 out of fit		Infit/Outfit indices	All within the +2;-2 range	

Note: The order of the learners' names is presented in descending order of Rasch measure scores in the post-test. The mean for item measure set to zero and Units per Logit=1 for the pre-and post-test (UIMEAN=0 and USCALE=1)

As shown in Table 7.10, there is a good reliability for both person and item measures in the pre- and post-learner achievement tests. The person reliability provides an estimate on the ability of the person to respond to the whole test. Both pre- and post-tests proved to be reliable at 0.60 and 0.73 in the pre- and post-tests, respectively. The item reliability measures were also found acceptable at 0.73 and 0.83 logits in the pre- and post-test, respectively. These are in both tests, above the generally recognized standard of 0.7 for Cronbach, indicating the replicability of the items. It can also be observed from Table 7.10 that most learners' pattern of responses was found to be fitting with the 'IN. ZSTD' and 'OUT.ZSTD' within the acceptable range of +2 to -2 for both pre- and post- tests. In the pre-test, one learner's response (NALD) was found to be out of fit. This is observed in the learner's 'OUT.ZSTD' value of 2.05, which is slightly outside the line of fit. The results show a higher Rasch person measures in the post-test than the pre-test Rasch person measures. The post-test person measure means of 1.06 from a lower pre-test person measure mean

of -1.08 is indicative of an improvement in the learners' conceptual understanding and performances.

iii. Rank order for Item Rasch measures

Similar to the case of Noma's learners,' the rank order for items difficulties is presented in this section to analyze the extent to which the learners responded to the items. Table 7.11 presents the Rasch item measures in terms of the rank of their difficulty.

Table 7. 11: Ranked Rasch item measures for Lerato's learners' pre-and post-achievement tests

Pre-test		Post-test	
Item	**Item measure**	**Item**	**Item measure**
Item 11	3.29	Item 4	2.54
Item 4	1.99	Item 2	0.37
Item 5	1.99	Item 10	0.37
Item 7	1.11	Item 11	0.37
Item 9	0.52	Item 3	-1.78
Item 6	0.52	Item 5	-1.78
Item 2	0.52	Item 9	-1.78
Item 10	0.52	Item 1	-3.03
Item 8	-0.73	Item 6	-3.03
Item 1	-1.44	Item 7	-3.03
Item 3	-1.44	Item 8	-3.03

Note: The mean for item measure set to zero & Units per Logit=1 for the pre-and post-test (UIMEAN=0 and USCALE=1).

As mentioned earlier, the Rasch measure values give the extent of the difficulty experienced by the participant learners responding to each item, where the higher Rasch measures show that the item was ranked as more difficult. For example, item 4, with a post Rasch measure of 2.54, is ranked as the most difficult in this test, whilst items 1, 6, 7, and 8 were the easiest with the lowest Rasch measures of -3.03 logits each.

A glance at the results on Table 7.11 shows that the learners reveal an increase in conceptual understanding in their post-achievement test as portrayed by the decrease in the level of difficulty of most items. Item 11, for example was in the pre-test ranked as the most difficult item for the learners, with a Rasch measure of 3.29 logits. In the post-achievement test, the Rasch measure for the same item was calculated at 0.37 logits, indicating a change in learner conceptual understanding, which affected their performance.

Similar to Noma's case, the rank order for the pre-and post-test Rasch measures is presented side-by-side in Table 7.12 below. This enables for the similarities and differences in the rankings of the items before and after Lerato's teaching to be analyzed and explained.

Table 7. 12: Pre and Post-test rank order Rasch measures for the items compared

Learner achievement test	Item 11	Item 4	Item 5	Item 7	Item 9	Item 6	Item 2	Item 10	Item 8	Item 1	Item 3
Pre	3.29	1.99	1.99	1.11	0.52	0.52	0.52	0.52	-0.73	-1.44	-1.44
Post	0.37	2.54	-1.78	-3.03	-1.78	-3.03	0.37	0.37	-3.03	-3.03	-1.78

The results presented in Table 7.12 show that the items in the pre- and post-achievement tests were similarly ranked. The item measures for items 11, 4, 5 and 7 show that the learners found these as the most difficult items in the pre-test. Although, the difficulty of the four items decreased after Lerato's teaching, items 11 and 4 were still found as more difficult for the learners, as seen by the positive item measures. Also identifiable from Table 7.12 is that the Rasch item measures were higher in the pre-test compared to those in the post-test which could be an indication of an improvement in learner conceptual knowledge and understanding of the test-items.

To explain further the development in learner conceptual understanding Figures 7.5 and 7.6 present the responses of Lerato's learners from the pre- and post-achievement tests. The responses portrayed are those based on item 11 on the tests. The learners' responses to items 10 and 11 were based on the following chemical equation which is said to be at a state of chemical equilibrium: $3X_{2(g)} \leftrightarrow 2X_{3(g)}$. Item 10 required the learners to identify, from a given list of responses, what the effect of increasing the amount of X_3 will have to the amount of X_2. Item 11 was a follow-up to the response given for item 10, to explain the learners' choice of the response using the Le Chatelier's Principle.

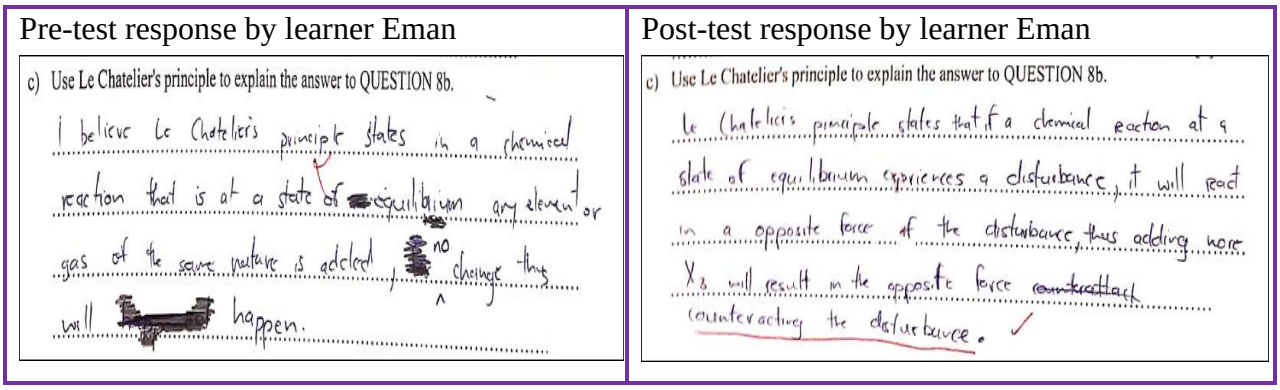


Figure 7. 5: Lerato's learner Eman's pre and post-test written response for item 11

The response given in the pre-test shows that the learner does not understand or know what the Le Chatelier's Principle is all about. In the last line of the response, the learner indicates that no change will happen to the reaction when the amount of one of the reacting substances is added within the system. The post-test response however shows some form of understanding in the learner's reasoning. The last line where the learner indicates that the system will act in such a way that counteracts the disturbance made reveals the learner's conceptual increase on the aspect demonstrated by the item. A response by learner Meli on the same item is presented in Figure 7.6 below.

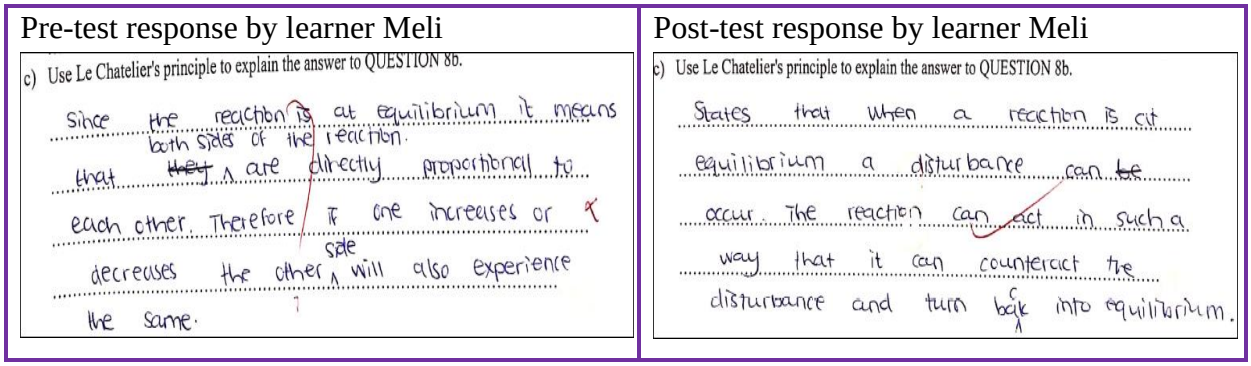


Figure 7. 6: Lerato's learner Meli's pre and post-test written response for item 11

In the pre-test, the response given by the learner is too broad and does not give a sense of understanding of the effect of a disturbance. The response by Meli on the post-test however shows an improved understanding of the concept as Meli indicates that the reaction always acts to counteract the disturbance. A follow-up point made by Meli which states that the reaction will re-instate Chemical Equilibrium is another highlight showing a conceptual knowledge gain in the post-test. Although both learners' post-test responses do not go to the extent of showing whether

there will be an increase or decrease in the amount of $X_{2(g)}$, the responses given demonstrate an improved understanding thereof.

iv. Explaining Lerato's learners' person ability

Figure 7.7 shows Lerato's learners' person ability measures pictorially on a variable map. Similar to Noma's learners, this allows for one to explain the ability of Lerato's learners to respond to items of different difficulty levels. The map presented in Figure 7.7 includes the pre-and post-test estimates together. Learner identifier codes with the letters only were the pre-test codes; the letters combined with the numbers were used as post-test codes for the learners.

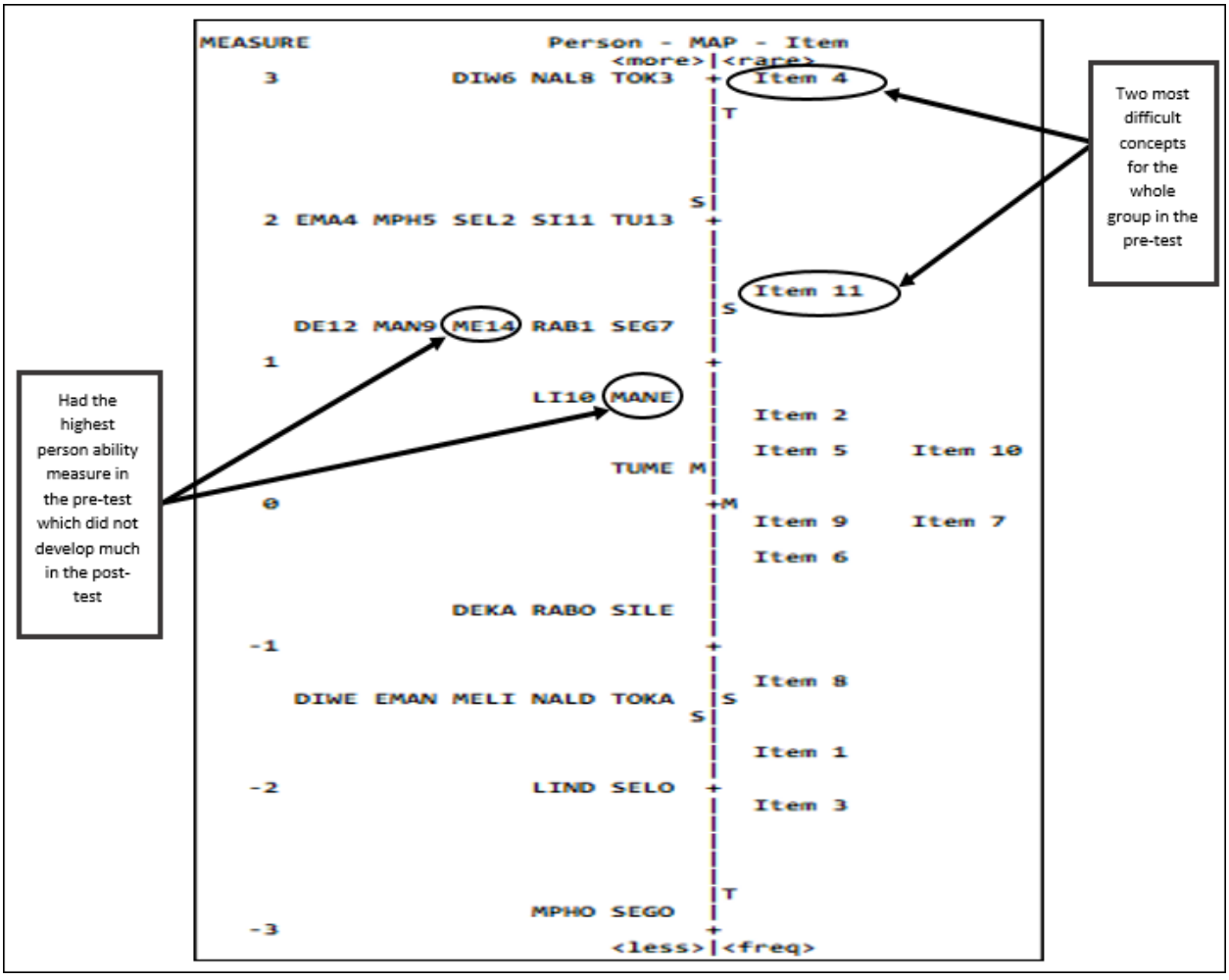


Figure 7. 7: A variable map for Lerato's learners pre- and post-achievement test Rasch measures

The results from Figure 7.7 show that in the pre-test, learner MANE had the highest person measure of about 0.8 logits. This indicated his ability to respond to 9 items within the test. This suggests that with his ability level, he would find it difficult to respond to only two items within

the test. MANE's post-test ability measure however did not reveal much improvement at around +1.8 logits. Almost all the learners in Lerato's class had a negative pre-test measure, with a limited ability to respond to most items of the test. A great improvement is observed across all the learners' post-test measures, where they all had a measure above +1 logits except for one learner, LI10, whose ability measure is located at around +0.8 logits.

v. Comparison of Rasch measures for significance difference

The summary of the anchored Rasch person measures and standard error for the pre- and post-achievement tests is presented in Table 7.13. The Rasch person measures were first anchored to produce stacked data (Mavhunga, 2012), which is further analysed for significance difference using the Wilcoxon Paired Signed Rank test. Subjecting this data to WPRT enabled for the measurement of the magnitude of the difference between the paired data (Whitley & Ball, 2002). As alluded to in section 7.1.1, the use of WPRT is considered suitable for use in the analysis of the small size sample; hence it is used in this study.

Table 7. 13: Stacked data- Person measures from anchored pre-and post-test

Learner	Pre-learner achievement test		Post-learner achievement test	
	Rasch measure	Error	Rasch measure	Error
TOKA	1.23	0.83	3.58	1.16
DIWE	0.63	0.83	3.58	1.16
NALD	-0.50	0.83	3.58	1.16
SELO	-0.50	0.95	2.54	0.91
EMAN	-0.50	0.83	2.54	0.91
MPHO	-1.13	1.22	2.54	0.91
SILE	-1.13	0.77	2.54	0.91
TUME	-1.13	0.76	2.54	0.91
RABO	-1.13	0.77	1.80	0.81
SEGO	-1.13	1.22	1.80	0.81
MANE	-1.90	0.79	1.80	0.81
DEKA	-1.90	0.77	1.80	0.81
MELI	-3.04	0.83	1.80	0.81
LIND	-3.04	0.95	1.18	0.77
MEAN	-1.08		2.54	

The results obtained from subjecting stacked Rasch measures to the WPRT are presented in Figure 7.8.

Pre-test Person measures	Anchored Post-test person measures	Diff=(Yi-Xi)	Abs(Diff)	Rank	Signed	T	105
1.23	3.58	2.35	2.35	1	-1	n	14
0.63	3.58	2.95	2.95	4	-4	α	0.05
-0.5	3.58	4.08	4.08	12	-12	Z	3.3
-0.5	2.54	3.04	3.04	5.5	-5.5	Reject Null at	0.05
-0.5	2.54	3.04	3.04	5.5	-5.5	p	0.00048
-1.13	2.54	3.67	3.67	8	-8		
-1.13	2.54	3.67	3.67	8	-8		
-1.13	2.54	3.67	3.67	8	-8		
-1.13	1.8	2.93	2.93	2.5	-2.5		
-1.13	1.8	2.93	2.93	2.5	-2.5		
-1.9	1.8	3.7	3.7	10.5	-10.5		
-1.9	1.8	3.7	3.7	10.5	-10.5		
-3.04	1.8	4.84	4.84	14	-14		
-3.04	1.18	4.22	4.22	13	-13		

Figure 7. 8: Summary for calculation of significance difference for Lerato's learners' performances

Figure 7.8 shows that the p-value is 0.00048 which is smaller than the significance level of 0.05. This indicates a significance difference at 95% (0.05) level between Lerato's learners' pre-test and post-test measures. The results imply that the conceptual understanding of the learners from Lerato's class improved significantly with 95% confidence following his teaching of the Chemical Equilibrium concepts.

THE CASE OF SARA'S LEARNERS

(ii) A performance analysis of raw scores

Table 7.14 displays the achievement test scores for the learners taught by Sara. The class was a cohort of twelve grade 14 learners. Two of them did not write the pre-test and were thus excluded from the class population results presented in Table 7.14 which is a review of the learners' achievement scores and a display of the knowledge gains for each learner.

Table 7. 14: Displaying learners' content knowledge gains on chemical equilibrium concepts: Sara's class

Learner code	Raw pre-test score (%)	Raw post-test score (%)	Percentage gain (%)
LERA	25	83	58
KAMO	25	83	58
TATO	25	75	50
BUKA	33	83	50
KEKA	33	75	42
MBIZ	42	83	41
KALO	42	83	41
TEBO	33	67	34
LESO	42	75	33
MAEK	58	83	25
TEKO	58	75	17
ZIMA	67	75	8
Average scores	**42**	**75**	**33**

Table 7.14 above shows that 92% of the learners scored between 25% and 58% in their pre-test. Eight percent of the participant learners scored 67% in the pre-test. On the other hand, all the learners (100%) scored above 60% in their post-test, with their scores ranging between 67% and 83%. One learner scored 67% in the post test, whilst all the others scored between 75% and 83%. Looking closely at column 4, it can be observed that all the learners portrayed knowledge gains in their post-test, ranging between 8% and 58%.

(iii) Raw scores converted into Rasch measures

Similar to Noma and Lerato's learners, the pre- and post-test raw scores by Sara's learners were run through the Rasch model to produce Rasch measures. The person Rasch measures are presented in Table 7.15.

Table 7. 15: The Rasch person scores of the pre- and post-achievement test for Sara's learners

Learner code	Pre-learner achievement test			Post-learner achievement test		
	Rasch person measure	*Fit statistics*		Rasch person measure	*Fit statistics*	
		IN. ZSTD	OUT. ZSTD		IN. ZSTD	OUT. ZSTD
KAMO	-2.44	1.30	1.17	2.44	-0.70	-0.43
MBIZ	-0.08	-1.01	-0.66	2.44	-0.70	-0.43
MAEK	2.51	-0.83	-0.37	2.44	0.84	0.53
BUKA	-.118	-1.34	-0.24	2.44	0.68	0.27
KALO	-0.08	-0.18	-0.27	2.44	0.84	0.53
LERA	-2.44	1.11	0.72	1.34	-0.44	-0.56
ZIMA	-0.08	-1.01	0.66	1.34	-0.89	-0.89
TATO	-2.44	1.11	0.72	1.34	-0.06	-0.12
KEKA	-1.18	-1.34	-0.24	1.34	0.27	0.77
TEKO	2.51	-0.83	-0.37	1.34	1.23	1.20
TEBO	-1.18	-1.34	-0.24	0.57	0.70	0.52
LESO	-0.08	-1.01	-0.66	0.57	-0.01	0.01
Reliability indices summarized	Rasch mean	-0.29		Rasch mean	1.67	
	Person reliability	0.61		Person reliability	0.73	
	Item reliability	0.80		Item reliability	0.86	
	Infit/Outfit indices	All within +2;-2 range		Infit/Outfit indices	All within +2;-2 range	

Note: The order in which the learners are presented is based on the descending order of post-test Rasch measures. The mean for item measure set to zero and Units per Logit=1 for the pre-and post-test (UIMEAN=0 and USCALE=1)

A good person and item reliability is demonstrated in the pre- and post-learner achievement tests, as shown in Table 7.15. The fit statistics measures, 'IN. ZSTD' and 'OUT.ZSTD' were found to fall within the acceptable range of +2 to -2 in the pre-and post-learner achievement test. When a person measure and an item difficulty fall within this statistical range, this indicates that they coherently work together in measuring a single construct, thus ensuring the validity of the test. The higher person measures for the post-achievement test compared to the personal measures of a pre-test show a positive shift in the performance of the learners in the test. The post-test person measure means of 1.67 from a lower pre-test person measure mean of -0.29 also signifies an improvement in the learners' conceptual performance.

iii. Rank order for Item Rasch measures

The Rasch model also allows for the establishment of the rank order of the items by providing the order of difficulty of the items. Table 7.16 presents the Rasch item measures in terms of the rank of their difficulty. It is important to recall that higher Rasch item measures imply that the item is ranked as most difficult whilst the lower value indicates that the item was easy to respond to.

Table 7. 16: Ranked Rasch item measures for Lerato's learners' pre-and post-achievement tests

Pre-test		Post-test	
Item	**Item measure**	**Item**	**Item measure**
Item 9	2.06	Item 5	0.90
Item 11	2.06	Item 11	0.90
Item 4	2.06	Item 7	0.46
Item 5	1.20	Item 2	-0.09
Item 7	0.62	Item 4	-0.92
Item 6	0.15	Item 6	-0.92
Item 2	-0.67	Item 9	-0.92
Item 10	-1.50	Item 10	-0.92
Item 8	-1.99	Item 1	-2.18
Item 3	-1.99	Item 3	-2.18
Item 1	-1.99	Item 8	-2.18

Note: The mean for item measure set to zero & Units per Logit=1 for the pre-and post-test (UIMEAN=0 and USCALE=1).

Table 7.16 shows that the learners had an increase in conceptual understanding in their post-achievement test as portrayed by the decrease in the level of difficulty of most items in the post-test compared to the high pre-test Rasch measures. A perfect example is that of item 9. A Rasch measure of 2.06 logits was recorded in the pre-test ranking as the most difficult item for the learners. The Rasch measure of the same item had reduced to -0.92 in the post-test; this indicates a change in learner conceptualization following Sara's teaching.

The rank order of the pre-and post-test item Rasch measures are presented side-by-side in Table 7.17. It assisted with the analysis of the similarities and differences in the ranking of the items before and after Sara's teachings.

Table 7. 17: Pre and Post-test rank order Rasch measures for the items compared

Learner achievement test	Item 9	Item 11	Item 4	Item 5	Item 7	Item 6	Item 2	Item 10	Item 8	Item 3	Item 1
Pre	2.06	2.06	2.06	1.20	0.62	0.15	-0.67	-1.50	-1.99	-1.99	-1.99
Post	-0.92	0.90	-0.92	0.90	0.46	-0.92	0.09	-0.92	-2.18	-2.18	-2.18

The item Rasch measures presented in Table 7.17 show that most of the items that the learners found difficult in the pre-test were also found difficult in the post-test. While those which were found easy in the pre-test were also found easy in the post-test. Table 7.17 shows that items 11, 5 and 7, which the learners found difficult in the pre-test, maintained positive Rasch measures in the post-test, whilst items 8, 3 and 1 which were easy in the pre-test remained the easiest for the group in the post-test. The level of difficulty of the items in the post-test (the most difficult in the pre-test) had decreased following Sara's teaching. This situation suggests an improvement in learner conceptual knowledge. Figure 7.9 provides the written responses of Sara's learners for item 9 which required the learners to define dynamic equilibrium. For the learners to be able to provide a correct answer to this item, they first needed to understand the concept of reversibility where both the forward and the reverse reactions occur simultaneously.

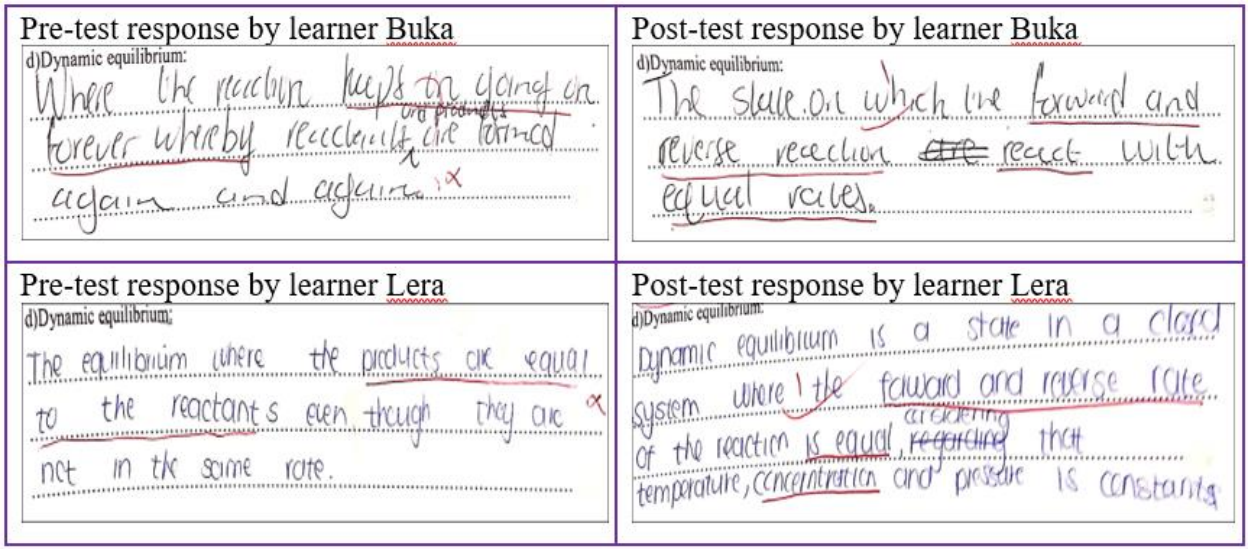


Figure 7. 9: Sara's learners' pre and post-test written responses for item 9

The pre-test response by learner Buka provides a sense of understanding of a concept of reversibility and the dynamic process. The answer is however partially correct as the learner does not include the "equilibrium concept" in the response. Learner Lera seems to think that the concentration of the reactants and products is equal. This is one of the common learner misconceptions on Chemical Equilibrium. The learner's misunderstanding of the concept is also observed in the same response as the learner states that reactions at dynamic equilibrium do not happen at the same rates. Both learners showed an improved understanding of the concept in their post-test responses as they were both able to indicate that dynamic equilibrium is a state reached by a reversible reaction where both forward and reverse reactions happen at equal rates. Lera's

response showed a much-extended conceptualization as he explained further that this happens in a closed system when all other factors (pressure, concentration and temperature) are kept constant. These conditions enable the occurrence of dynamic Chemical Equilibrium.

iv. Explaining Sara's learners' person ability

Figure 7.10 shows the person ability measures of Sara's learners on a variable map. This map, which presents both person ability measure and item difficulty, allows for one to explain the ability of persons to respond to the items of various difficulty levels. A similar strategy used to generate learner identifier codes for Noma and Lerato's learners was used for Sara's class. Those with letters only were the pre-test codes. The first 2 or 3 letters from the pre-test codes, combined with the numbers were used in the post-test.

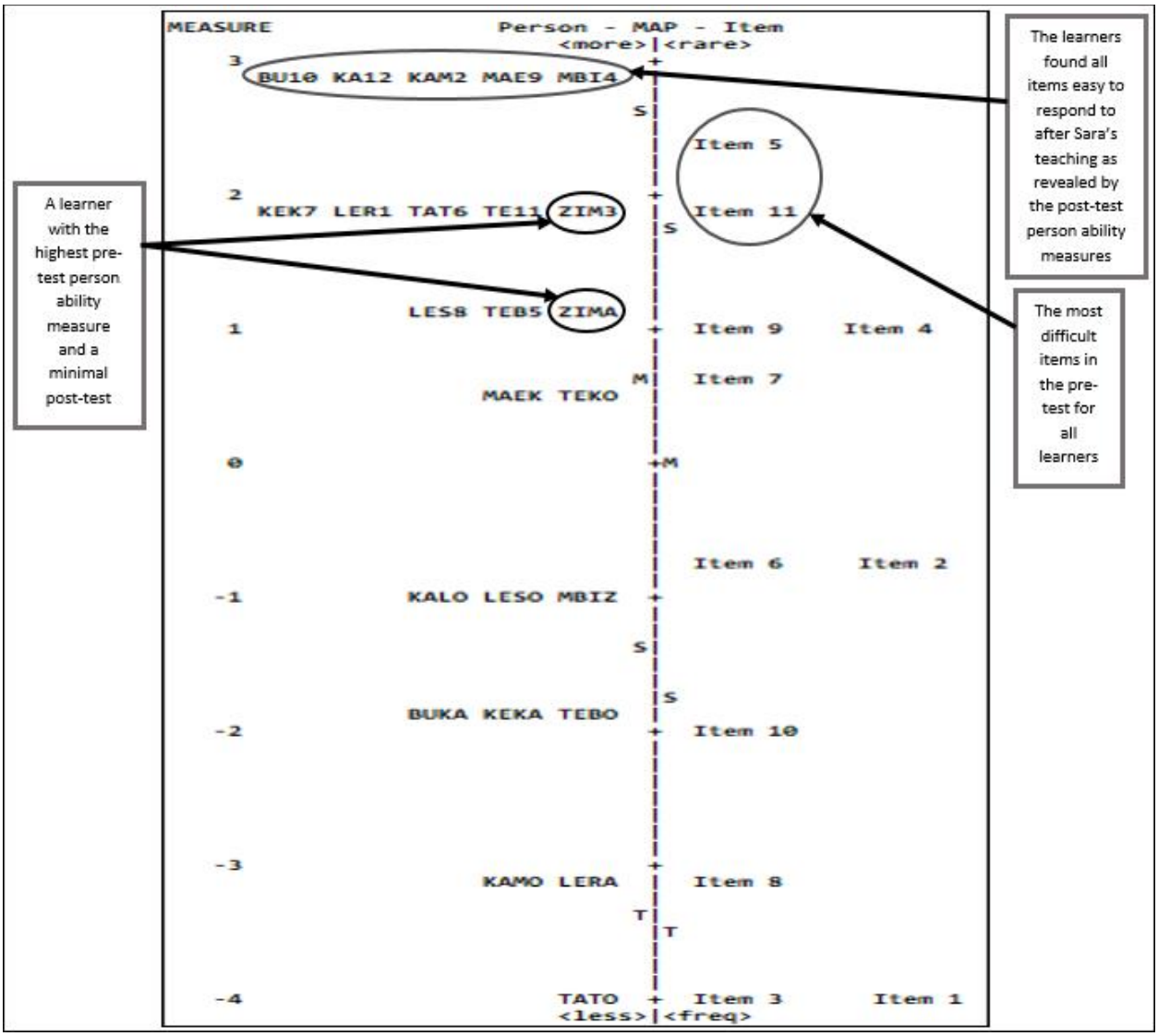


Figure 7. 10: A variable map for Sara's learners pre- and post-achievement test Rasch measures

Figure 7.9 shows that learner TATO had the lowest person ability measure in the pre-test compared to all learners in the group. He had a 50-50 chance of correctly responding to two items on the test. Learner ZIMA, on the other hand, had the highest person measure of about 1.2 logits. ZIMA's person ability shows that he found just two items difficult to answer in the pre-achievement test. Almost all the learners in Sara's class had a negative person ability measure in their pre-test except for the three learners: MAEK, TEKO and ZIMA. The post-test person ability measures for all the learners were above +1.0 logits. This situation is suggestive of an improvement in the ability to respond to items of varying difficulty. In the post-test as revealed by the person ability measures in Figure 7.9, five learners: BU10, KA12, KAM2, MAE9 and MBI4 responded to all the items in the test without any form of difficulty, following Sara's teaching.

v. Comparison of Rasch measures for significance difference

The summary of the anchored Rasch person measures and standard error for the pre- and post-achievement tests is presented in Table 7.18. The Rasch person measures were first anchored to produce stacked data and then subjected to the Wilcoxon Paired Signed Rank test to examine the significance difference.

Table 7. 18: Stacked data- Person measures from anchored pre-and post-test

Learner	Pre-learner achievement test		Post-learner achievement test	
	Rasch measure	Error	Rasch measure	Error
KAMO	-2.44	1.22	5.23	1.17
MBIZ	-0.08	1.06	5.23	1.17
MAEK	2.51	1.30	5.23	1.17
BUKA	-1.18	1.07	5.23	1.17
KALO	-0.08	1.06	5.23	1.17
LERA	-2.44	1.22	4.11	0.99
ZIMA	-0.08	1.06	4.11	0.99
TATO	-2.44	1.22	4.11	0.99
KEKA	-1.18	1.07	4.11	0.99
TEKO	2.51	1.30	4.11	0.99
TEBO	-1.18	1.07	3.12	1.00
LESO	-0.08	1.06	3.12	1.00
MEAN	-0.29		4.41	

Figure 7.11 displays the results of the analysis, using the Wilcoxon's Paired Rank Test (WPRT).

Pre-test Person measures	Anchored Post-test person measures	Diff=(Yi-Xi)	Abs(Diff)	Rank	Signed	T	78
-2.44	5.23	7.67	7.67	12	-12	n	12
-0.08	5.23	5.31	5.31	7.5	-7.5	α	0.05
2.51	5.23	2.72	2.72	2	-2	Z	3.1
-1.18	5.23	6.41	6.41	9	-9	Reject Null at	0.05
-0.08	5.23	5.31	5.31	7.5	-7.5	p	0.00222
-2.44	4.11	6.55	6.55	10.5	-10.5		
-0.08	4.11	4.19	4.19	4	-4		
-2.44	4.11	6.55	6.55	10.5	-10.5		
-1.18	4.11	5.29	5.29	6	-6		
2.51	4.11	1.6	1.6	1	-1		
-1.18	3.12	4.3	4.3	5	-5		
-0.08	3.12	3.2	3.2	3	-3		

Figure 7. 11: Summary for the calculation of significance difference for the performance of Sara's learners.

Figure 7.11shows that the p-value is 0.00222. This is smaller than the significance level of 0.05, suggesting a significance difference at 95% (0.05) level between the Rasch measure performances for the pre- and post-test of Noma's learners. This indicates that the conceptual understanding of Sara's learners on Chemical Equilibrium improved significantly with 95% confidence level, following her teaching.

7.3. Summary of the key findings in this Chapter

The main purpose of this study was to track the changes in the PPSTs knowledge acquired through the intervention (cTSPCK) which aimed at developing their TSPCK in lesson planning from a formal course, how this translated into plTSPCK, then enactment (eTSPCK) and its culminating overall impact on learner performance.

The discussions in this chapter focused on measuring and explaining the conceptual knowledge of each of the 3 PPSTs' learners according to their performance tests written before and after the teaching of Chemical Equilibrium as a topic. The findings reveal that the learners throughout the 3 PPST' lessons showed a positive and significant gain in the knowledge of Chemical Equilibrium concepts after the PPSTs' teaching. A significant difference at 95% level was obtained across the 3 PPSTs' learners' pre- and post-Rasch measure performance. First, the knowledge gain was observed from the raw scores across the PPSTs' learners. A significant increase from 21% pre-conceptual performance to 75% post-test performance was calculated from Noma's learners and shows an average gain of 54%. An increase from 27% to 76% and from 40% to 78% was observed from Lerato's and Sara's learners respectively; this is an average increase of 49% and 38% following their teaching. Summarized in Figure 7.11 is the pre- and post-test raw score performances for the 3 PPSTs' learners.

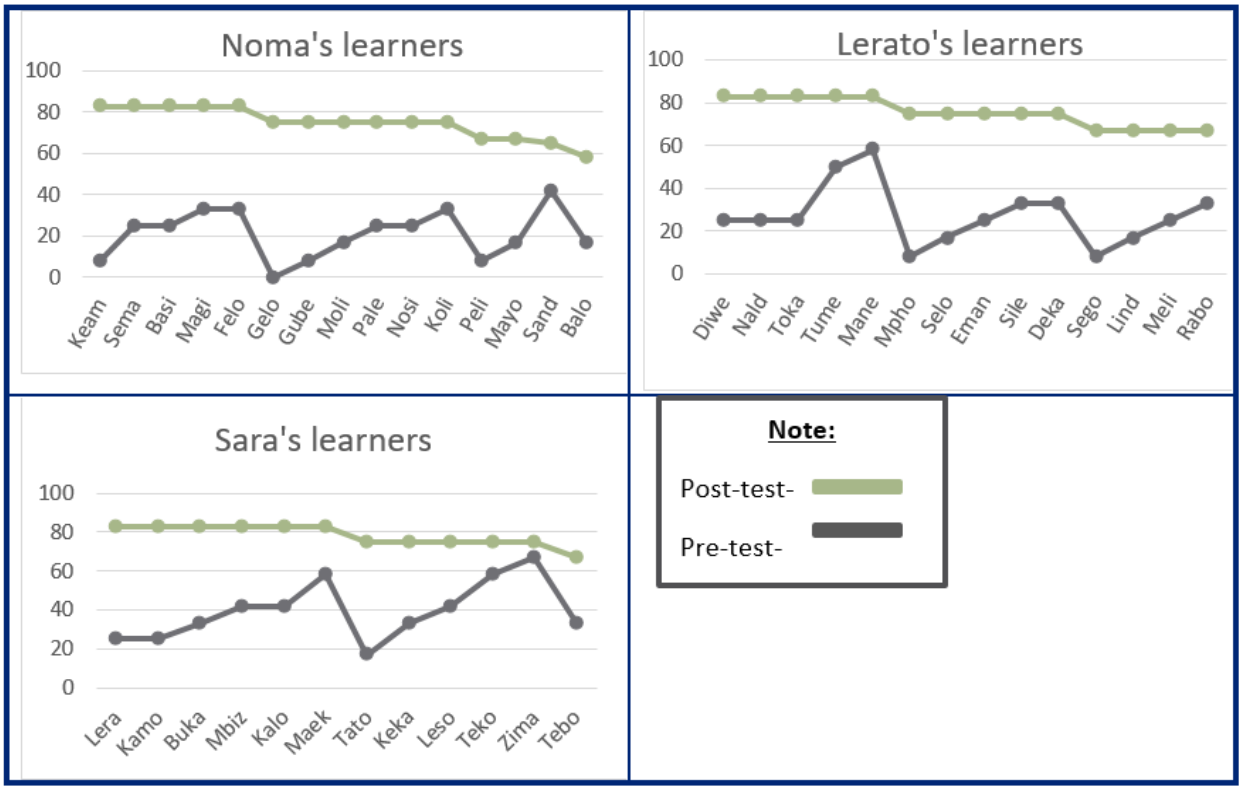


Figure 7. 12: The summarized content gains on Chemical equilibrium concepts across the PPSTs' learners

Figure 7.12 has all the graphs showing a knowledge gain in the post-test by the learners after each of the PPSTs' teaching. This suggests an increased conceptual understanding.

Secondly, person Rasch measures for all the learners changed from the mostly negative low ability to respond to items, as observed in the pre-test performance measures, to high positive person Rasch measures in the post-test performance. The positive person Rasch measures suggest an improvement in the learners' ability to respond to difficult items within the test, as was observed in the post-test measures following the PPSTs' teaching.

Chapters 5 and 6 focused on the PPSTs' plTSPCK and eTSPCK respectively while this chapter analyzed the learner performance. The next chapter, Chapter 8, examines the link, if any, that exists between the learners' conceptual performance and the PPSTs' eTSPCK, as the TSPCK experienced directly by the learners.

CHAPTER 8

UNDERSTANDING THE CORRELATIONS BETWEEN TEACHER KNOWLEDGE AND LEARNER PERFORMANCE

This chapter analyses the relationship between learner conceptual performances, and the PPSTs' eTSPCK on a chemistry topic, Chemical Equilibrium. This is done by analyzing the data to find the link between the performance of the learners in the post-test written after the PPSTs' teaching and the explanation of the related concepts considered to reflect the PPSTs' TSPCK.

8.0. Introduction

Chapters 5 and 6 examined the PPSTs' personal TSPCK in planning to teach (plTSPCK) and that enacted (eTSPCK) in their teaching of Chemical Equilibrium, respectively. Chapter 7 then analyzed the learners' performance on the same topic before and after the PPSTs' teaching. *With the main purpose of this study being to trace how the PPSTs translate their TSPCK in planning to teach (plTSPCK) into classroom context (eTSPCK) and* ***its possible effect on learner conceptual performance***. Chapter 8 then examines the link between learners' performance on Chemical Equilibrium concepts following the 3 PPSTs' teaching. Whilst acknowledging the presence of amplifiers and filters which influence the direct link between teacher knowledge and learner outcomes (Gess-Newsome, 2015), teacher knowledge and how teachers teach is recognized as impacting greatly on learner performance (Kind, 2018).

In order to examine the link between the PPSTs' TSPCK and learner outcomes, video recorded PPSTs' lessons which reveal their eTSPCK and their learners' performance in the pre-and post-tests were matched. This was done by identifying and analyzing the moments of teacher explanations in the lesson that reflected TSPCK, which were considered to be TSPCK episodes and matching these to the learners' performance. As discussed extensively in Chapter 3, a TSPCK episode is described as an explanation, by the teacher, which portrays a minimum interactive use of two TSPCK components (Mavhunga, 2018). All the identified eTSPCK episodes were scored and categorized using a validated eTSPCK rubric (Miheso, 2018) with the help of an independent rater to improve trustworthiness. According to the eTSPCK rubric, a basic TSPCK episode (denoted as a 1 on the rubric) is characterized by the presence of two different TSPCK components interacting in a teaching segment. A proficient TSPCK episode (denoted a 2) has three different TSPCK components interacting evidently. Lastly, a sophisticated episode (denoted by a 3) is

characterized by the presence of four different TSPCK components including the cases where three are different and the fourth is a repetition of one of the components. The PPSTs' eTSPCK was, in this case, considered more fitting as it was the closest demonstration of TSPCK that the learners were exposed to.

8.1. A Brief Summary on Methodology

The sample size in this analysis is a total of 46 participants. It comprised 43 physical science learners from 3 Johannesburg ex Model C high schools and a subset of 3 PPSTs. As described in Chapter 3, the contexts of the 3 schools are considered reasonably equivalent in that, the schools are located around the same area in Johannesburg, with a similar mix of student population, a similar mix of teachers and all drawing both teachers and learners from the same community. A summary of the key information for the participants in this Chapter is presented in Table 8.1.

Table 8. 1: The key information about the participant PPSTs and their learners

Pre-service teacher	**TSPCK episodes categories and quantities as identified in the lessons from Chapter 6**			**Learners per PPSTs' class**			
	Basic episode	Proficient episode	Sophisticated episode	Grade	Female	Male	Total
Noma	4	8	4	12	7	8	15
Lerato	6	10	9	12	7	7	14
Sara	4	10	12	12	5	9	14

All the PPSTs' lessons reflected a TSPCK episode profile containing all the three categories of eTSPCK namely, the basic, proficient and sophisticated TSPCK episodes to differing extents. As discussed in Chapter 3, the eTSPCK rubric simply captures and portrays the different categories of eTSPCK displayed in a lesson. It does not produce a single, summative score of the identified eTSPCK episodes which is in line with the understanding that each interactive use of TSPCK components to form an eTSPCK episode in a class, rather than the sum of the episodes, is important (Miheso, 2018). Naturally, there is a tendency to expect better quality with a TSPCK episode profile that shows higher quantities of proficient and sophisticated eTSPCK episodes. This is done in mindfulness that when the sequence of emergence of the identified eTSPCK episodes in a lesson is done, the basic eTSPCK, however low in the ranking of the eTSPCK episodes, tends to provide the building blocks that lead to a higher order eTSPCK or a collection of eTSPCK episodes scaffolding a complex explanation (Mavhunga and van der Merwe, 2020). The purpose here,

however, rested in capturing and portraying the PPSTs' eTSPCK and then comparing each profile to respective learner performance. Section 8.1.1 presents the data analysis procedure.

8.1.1. Data Analysis

The purpose of this chapter is to establish the possible link between the PPSTs' eTSPCK and learner outcomes. The scores for the PPSTs' eTSPCK were generated from recalling the qualitative scoring of the PPSTs eTSPCK profile derived from analyzing the recorded lesson videos in Chapter 6. Since these scores were qualitative in nature, they were first converted into quantitative linear measures by using the Rasch statistical software called, Winsteps. The episodes were read into the Rasch program as persons whereas the 5 TSPCK components were read in as items (see Appendices V, X and Z). The Rasch statistical analysis model is useful in transforming ordinal data into linear measures placed on an equidistant scale (Boone *et al*., 2014; Bond & Fox, 2015). The calculated PPSTs linear Rasch person measures were then used to conduct a statistical correlation analysis. The analysis was done in two sets, (i) first between each of the PPSTs' eTSPCK episode Rasch measures and their respective learners' Rasch person measures in the pre-test, then (ii) the analysis repeated with the post-learner achievement tests (see section 8.2.1 below).

8.2. eTSPCK and learner performance correlation analysis

8.2.1. Quantitative overview patterns of the correlation analysis between the PPSTs' eTSPCK episodes and learner performance

Because of a different number of variables that were paired, Rasch measures for the PPSTs' eTSPCK episodes and learner performance, a strategic random sampling was done in three batches in order to allow for all the variables to be paired. This was important to do because the correlation that compares two variables requires paired data sets when running the statistical correlations (Greasley, 2007). Through the use of a correlation analysis, the study estimated the Pearson correlation coefficient (r) of learner achievement versus each of the PPST's overall eTSPCK episodes across multiple batches. The correlation coefficient is widely used in research to describe the relationship between strength and direction of correlation between two variables that are being investigated (McMillan & Schumacher, 2014; Benesty, Chen, & Huang, 2008). The strength of correlation describes the magnitude of the association between the variables. On the other hand,

the direction refers to the signage of the association, revealing whether the association is positive or negative (McMillan & Schumacher, 2014). As alluded to in Chapter 3, the correlation coefficient of zero implies that there is no linear association between two variables being compared (McMillan & Schumacher, 2014; Schober, Boer, & Schwarte, 2018). Stronger linear relationships are explained between the variables whose correlation coefficients are closer to -1 or +1. A positive correlation exists when variables are directly associated whereby as the value of one variable increases, so does the value of the other variable (Schober *et al.*, 2018). A negative correlation coefficient, on the other hand, reveals an inverse association between the variables whereby as the value of one variable increases, a decrease occurs in the value of the other variable (Schober *et al.*, 2018). Figure 8.1 presents the overall correlation analysis findings. The first 3 batches in the green shaded columns represent the correlation results between the PPSTs' eTSPCK episodes and learner pre-test performances, while the second set of batches, in the pink shaded columns, display the results of the correlation between the PPSTs' eTSPCK episodes and learner post-test performances. These are subsequently presented in detail in the sections that follow.

NOMA

Correlations

		Learners' Pre-Test Person measures	Batch 1: Noma's overall Episodes	Batch 2: Noma's Overall Episodes	Batch 3: Noma's Overall Episodes	Learners' Post-Test Person measures	Batch 1: Noma's Overall Episodes	Batch 2: Noma's Overall Episodes	Batch 3: Noma's Overall Episodes
Noma's Overall episodes	Pearson Correlation	1	-.188	-.207	-.200	1	.690	.660	.725
	Sig. (2-tailed)		.423	.526	.501		.020	.010	.018
	N	15	15	15	15	15	15	15	15

Pre-test average

r= -0.198 (*p* = 0.483)

negligible correlation

Post-test average

r = 0.688 (*p* = 0.016)

Moderate positive correlation

LERATO

Correlations

		Learners' Pre-Test Person measures	Batch 1: Lerato's Overall Episodes	Batch 2: Lerato's Overall Episodes	Batch 3: Lerato's Overall Episodes	Learners' Post-Test Person measures	Batch 1: Lerato's Overall Episodes	Batch 2: Lerato's Overall Episodes	Batch 3: Lerato's Overall Episodes
Lerato's Overall episodes	Pearson Correlation	1	-.066	-.294	-.156	1	.817	.768	.780
	Sig. (2-tailed)		.823	.308	.670		.045	.034	.010
	N	14	14	14	14	14	14	14	14

Pre-test average

r= -0.172 (*p* = 0.600)

negligible correlation

Post-test average

r = 0.788 (*p* = 0.03)

High positive correlation

SARA

Correlations

		Learners' Pre-Test Person measures	Batch 1: Sara's Overall Episodes	Batch 2: Sara's Overall Episodes	Batch 3: Sara's Overall Episodes	Learners' Post-Test Person measures	Batch 1: Sara's Overall Episodes	Batch 2: Sara's Overall Episodes	Batch 3: Sara's Overall Episodes
Sara's Overall Episodes	Pearson Correlation	1	-.029	-.285	-.307	1	.871	.856	.816
	Sig. (2-tailed)		.930	.297	.333		.010	.015	.013
	N	12	12	12	12	12	12	12	12

Pre-test average

r = -0.207 (*p* = 0.52)

negligible correlation

Post-test average

r = 0.841 (*p* = 0.013)

High positive correlation

Figure 8. 1: Overall correlation between the PPSTs' eTSPCK and learner performances

Figure 8.1 displays the overall quantitative findings of the correlation between the Rasch person measures of each of the PPSTs' overall eTSPCK episodes versus learner person Rasch measures in the pre-and post-learner achievement tests on Chemical Equilibrium. As alluded to in Chapter 3, there are certain descriptors that are used to interpret correlation coefficients. The descriptors are ***negligible*** for the values below **+/- 0.3**; ***low*** for the values ranging from **+/- (0.3 to 0.5); *moderate*** for the values ranging between **+/- (0.5 to 0.69)**; ***high*** and ***very high correlations*** for values ranging between **+/-** (**0.70 to 0.90)** and **+/-** (**0.90 to 1.00)** respectively. Consequently, a stronger association between two variables is explained by the Pearson correlation coefficient (r) that is closer to +1 or -1.

Figure 8.1 shows an existence of an insignificant correlation between all the PPSTs' eTSPCK episodes and the learners' pre-test performance with the average Pearson correlation coefficients r = -0.198 (p = 0.483), r = -0.172 (p = 0.600) and r = -0.207 (p = 0.52) for Noma, Lerato and Sara's case respectively measured at a significance level α = 0.05. The strength and negative signage at the alpha values higher than the significant level of 0.05 suggest the presence of an insignificant negative negligible correlation between the PPSTs' eTSPCK and the learner pre-test performance. The negative sign indicates an inverse relationship between the PPSTs' eTSPCK and learner performance in the pre-test whilst the statistically insignificant and negligible (r < -0.30) correlation shows an absence of a considerable relationship between the variables. An insignificant correlation between the PPSTs' eTSPCK and learner pre-test performances provides confirmation that the learners had not received any teaching on this topic prior to the pre-test. This suggests that the gains by learners in the post-achievement tests may be linked to the PPSTs' teachings.

A significant correlation was established between the PPSTs' eTSPCK and learner post-tests performance as observed by the average Pearson correlation coefficient r = 0.688 (p = 0.016), r = 0.788 (p = 0.03) and r = 0.841 (p = 0.013) for Noma, Lerato and Sara's cases respectively, measured at a significance level α = 0.05.The strength and direction of the Pearson correlation coefficients at a significant level much lower than α = 0.05 indicated the presence of a statistically significant and moderate to high correlation (between r = +0.50 and r = +0.90) between the PPSTs' eTSPCK and the learners' post-test performance. A positive signage indicates a direct relationship between the PPSTs' eTSPCK episodes and learner performance in the post-test. Accordingly, the

statistically significant and moderate to high positive correlation shows the presence of a considerable relationship between the variables.

The detailed results of the correlation analysis are presented in the section below. They are presented case-by-case between each of the PPST's eTSPCK and the learners' performance. The analysis was done in two sections: (i) First, the quantitative analysis of the correlation between each of the PPSTs' eTSPCK episode Rasch measures and their respective learners' Rasch person measures, (ii) second, the qualitative analysis on the correlation between the PPSTs' eTSPCK and learner performances to collaborate the quantitative findings.

THE CASE OF NOMA AND HER LEARNERS

(i) A quantitative analysis of the correlation between PPSTs' eTSPCK and learner performances.

A total of 16 eTSPCK episodes were identified in Noma's recorded video on the teaching of Chemical Equilibrium concepts, as analyzed in Chapter 6. Table 8.2 presents the content covered per teaching segment, the resultant eTSPCK episode and the rubric score/level recalled from the analysis done in Chapter 6. An additional information of the newly calculated Rasch person measures for the eTSPCK episodes including the fit statistical parameters are also presented on the last three columns (C-6, C-7 and C-8).

Table 8. 2: Noma's eTSPCK episodes converted into Rasch person measures

C-1	C-2	C-3	C-4	C-5	C-6	C-7	C-8
Time (mins)	Teaching segments	Emerging episodes	TSPCK Episode Category	TSPCK Rubric level	Rasch Person measure	*Fit statistics* IN. ZSTD	OUT. ZSTD
0-3	Characteristic of chemical reactions	LPK/CS	Basic	1	-0.01	1.11	1.13
3-10	Types of systems	LPK/R/CS/R	Sophisticated	3	2.58	MAX	MAX
10-17	Reversibility of reactions	LPK-R/CS/WD/R/LPK	Sophisticated	3	2.58	MAX	MAX
17-25	Rates at CE: rate time graph	LPK/WD/R	Proficient	2	1.16	0.54	0.52
25-33	Explaining rate time graph	R/LPK-WD	Proficient	2	1.16	-0.51	-0.60
33-35	Dynamic CE	R/CS/WD	Proficient	2	1.16	1.81	1.79
35-42	Concentrations at CE: concentration time graph	LPK/WD/R	Proficient	2	1.16	-0.51	-0.60
42-50	Factors affecting CE: Temperature	CS/LPK-CS/WD	Sophisticated	3	2.58	MAX	MAX
50-57	Effect of temperature continued	LPK-R/WD	Proficient	2	1.16	-0.51	-0.60
60-65	Effect of Pressure	R/LPK/WD/CS	Sophisticated	3	2.58	-0.51	-0.60
65-72	The Le Chatelier's Principle	CS/WD	Basic	1	-0.01	1.81	1.79
72-78	Change in concentration	R/LPK-WD	Proficient	2	1.16	-0.51	-0.60
78-88	Evaluation: effect of concentration	R/LPK-CS/WD	Sophisticated	3	2.58	-0.51	-0.60
88-97	Effect of pressure	LPK-CS/R	Proficient	2	1.16	0.54	0.52
97-101	General effect of a disturbance	R/CS	Basic	1	-0.01	1.81	1.79
101-105	The dynamic nature of CE	R/WD/LPK	Proficient	2	1.16	-0.51	-0.60
Reliability indices summarized		Rasch mean 1.04 Person reliability 0.00 Item reliability 0.74 Infit/Outfit indices 3 out of fit					

Note: LPK-Learner Prior Knowledge; CS-Curricular saliency; WD-What is difficult to teach or understand; R-Representations; CTS-Conceptual teaching strategies. The episodes are presented in descending order of the Rasch person measures. The mean for the item measure is set to zero & Units per Logit=1 for the tests (UIMEAN=0 and USCALE=1)

The fit statistical parameters represented by IN. ZSTD and OUT. ZSTD measure the coherence of the person measures to the level of the difficulty of the items. In this specific analysis, the fit statistics estimated the probability of the PPST to display the eTSPCK episodes that portray the interactions between multiple TSPCK components. The statistical fit values are considered acceptable and good when they are within the range of -2 and +2 (Boone *et al*., 2014). This would be an indication that both the item and person measures work coherently together to measure a single construct. The values below -2 and above +2 are regarded as not fitting the Rasch model.

Table 8.2 reveals three indices that are statistically out of fit. They are labeled as MAX. The outfit index reflects items that are quite distant from a person's ability level and therefore not expected to be achieved (Boone & Rogan, 2005, p. 34). MAX in this case refers to the extreme explanations by persons (the PPSTs). Looking at the column of "emerging episodes", it can be observed that those are sophisticated episodes with the highest person Rasch measure (2.58), which also portray

a repeat of one of the TSPCK components. Perhaps, the system read this as unconventional and unexpected, as it was observed in only a fewer number of episodes. For example, for the first episode (LPK/CS) in Table 8.2, each component appears ones in the interaction, and hence were each entered as "1" into the Excel spreadsheet (1-LPK and 1-CS). The second episode (LPK/R/CS/R) on the other hand was added as 1-LPK, 2-R and 2-CS. So, while most of the episodes had one component read ones, the highlighted episodes labeled as MAX had at least one component each, read twice, thus making them different from the majority of the episodes. Consequently, the Rasch model regarded these combinations of eTSPCK components as complex and uncommon.

Noma's learners' pre-and post-achievement Rasch person measures were recalled from Chapter 7 and presented again (without any additional information) in Table 8.3 below for ease of reference.

Table 8. 3: Noma's learners' Rasch person measures imported as Table 7.5 in Chapter 7

Learner code	Pre-learner achievement test			Post-learner achievement test		
	Rasch person measure	*Fit statistics*		Rasch person measure	*Fit statistics*	
		IN. ZSTD	OUT. ZSTD		IN. ZSTD	OUT. ZSTD
KEAM	-2.47	-0.35	-0.24	2.65	0.28	-0.04
BASI	0.03	-0.04	-0.27	2.64	-0.36	-0.49
FELO	0.03	-0.04	0.27	2.64	0.65	1.23
SEMA	0.65	1.46	1.13	2.64	0.65	1.23
GUBE	-2.47	-0.35	-0.24	1.73	0.30	-0.13
GELO	-2.47	-0.35	-0.49	1.73	-0.18	-0.11
MOLI	-1.43	-1.35	-0.80	1.73	0.13	1.57
PALE	-0.65	-1.64	-0.60	1.73	-0.38	-0.46
NOSI	-0.65	1.46	1.13	1.73	-0.38	-0.46
SAND	0.69	1.17	1.34	1.12	-1.08	-1.08
MAGI	0.03	-0.85	-0.77	1.12	-0.20	-0.37
MAYO	-1.43	-1.35	-0.80	1.12	0.43	0.06
BALO	-1.43	-1.35	-0.80	0.62	1.08	0.93
PELI	-2.47	0.69	0 .49	0.18	0.39	0.19
KODI	0.03	-1.41	-1.12	-0.24	0.68	0.22
Reliability indices summarized	Rasch mean	-1.11		Rasch mean	1.54	
	Person reliability	0.74		Person reliability	0.77	
	Item reliability	0.77		Item reliability	0.80	
	Infit/Outfit indices	All within +2;-2 range		Infit/Outfit indices	All within +2;-2 range	

Note: The names of the learners are presented in descending order of Rasch measures in the post-test. The mean for item measure set to zero & Units per Logit=1 for the tests (UIMEAN=0 and USCALE=1)

The high Rasch person measures (with zero as a reference) indicate a high probability for the participant to respond to the item correctly whilst the below zero Rasch person measures imply a lower probability for the participant to answer the item correctly.

The Rasch person measures for Noma's eTSPCK episodes from Table 8.2 and the learners Rasch person measures from Table 8.3 were all run through the Statistical Package for the Social Sciences (SPSS) to calculate the Pearson correlation coefficient (*r*) (Aldrich, 2018). As it is alluded to above, the correlation analysis that compares two variables requires paired data sets when running the statistical correlations (Greasley, 2007). Because of a different number of variables that were paired, 16 eTSPCK episodes and 15 learner performance scores, a strategic random sampling was done in three batches in order to allow for all the variables to be paired. Figure 8.2 presents the results of the Pearson correlation analysis.

NOMA

Correlations

		Learners' Pre-Test Person measures	Batch 1: Noma's overall Episodes	Batch 2: Noma's Overall Episodes	Batch 3: Noma's Overall Episodes	Average	Learners' Post-Test Person measures	Batch 1: Noma's Overall Episodes	Batch 2: Noma's Overall Episodes	Batch 3: Noma's Overall Episodes	Average
Noma's Overall episodes	Pearson Correlation	1	-.188	-.207	-.200	-.198	1	.690	.660	.725	.688
	Sig. (2-tailed)		.423	.526	.501	.483		.020	.010	.018	.016
	N	15	15	15	15	15	15	15	15	15	15

Figure 8. 2: Noma's overall eTSPCK episodes and her learners' Rasch Person measures

Figure 8.2 shows that the Pearson correlation coefficients between Rasch measures of Noma's eTSPCK episodes and her learners' pre-test performances were r_1 = -0.188 (p_1 = 0.423), r_2= -0.207 (p_2 = 0.526) and r_3 = -0.200 (p_3 = 0.501), calculated at a significant level α = 0.05. An average correlation coefficient of r= -0.198 (p = 0.483) was calculated between Noma's eTSPCK episodes and her learners' pre-test performances. The strength and the signage (negative) which determine the direction of the correlation coefficient (r) at the alpha values that are much higher than the significant level of 0.05, indicate the presence of an insignificant and negligible correlation between Noma's eTSPCK and the learners' pre-test performance. The calculated average Pearson correlation coefficient is below r = -0.30, which is the agreed cutoff for very low and hence negligible correlations between two variables (Hinkle *et al*., 2003). Contrary to this, the Pearson correlation coefficients of r_1 = 0.690 (p = 0.020), r_2 = 0.660 (p = 0.010) and r_3 = 0.725 (p = 0.018) were calculated in the post-test. An average correlation coefficient of r = 0.688 (p = 0.016) was calculated between Noma's eTSPCK episodes and her learners' post-test performances. The resultant strength and direction of the correlation coefficient for all the three batches, at the alpha values much lower than the significant level of α = 0.05 indicated the presence of a statistically significant and moderate correlation between Noma's eTSPCK and the learners' post-test performance. The calculated average correlation coefficient is within the established cutoff range of r = **+(0.5 to 0.69)** which classifies the correlation as moderate. A positive correlation in this case suggests a direct linear relationship between Noma's eTSPCK and learner performance in the post-test whilst the significantly moderate correlation value shows the presence of a fairly reasonable relationship between the two variables.

(ii) A qualitative analysis of the correlation between PPSTs' eTSPCK and learner performances

This section presents a qualitative analysis of the link between Noma's eTSPCK and the learners' conceptual performance on Chemical Equilibrium. Noma had a total of 15 learner participants in her class. The highest possible test performance for a total group of 15 learners would be the total number of correct scores on each item in the pre-and post-test. Table 8.4 presents Noma's learners' conceptual performances in the pre-and post-learner achievement test items and her eTSPCK episodes linking directly to those test items. The highlighted items on Table 8.4 correspond to the eTSPCK episodes that were calculated as out of fit through the Rasch analysis model.

Table 8. 4: Noma's eTSPCK episodes against her learners' conceptual performances

Test Item	Noma's learners' performances				Noma's eTSPCK	
	Pre-test	*Post-test*	*Knowledge gain*	*Percentage gain (%)*	*TSPCK episode*	*TSPCK category*
Item 4	0	12	12	80	R/LPK/WD/CS	Sophisticated
Item 5	0	11	11	73	LPK/WD/R/CS	Sophisticated
Item 7	3	13	10	67	LPK/R/CS/R	Sophisticated
Item 6	3	13	10	67	LPK/R/CS/R	Sophisticated
Item 1	3	13	10	67	LPK/WD/R	Proficient
Item 9	4	14	10	67	R/CS/WD	Proficient
Item 11	0	9	9	60	CS/WD	Basic
Item 8	6	12	6	40	LPK-R/CS/WD/R/LPK	Sophisticated
Item 2	1	6	5	33	CS/LPK-CS/WD	Sophisticated
Item 3	10	13	3	20	LPK/WD/R/CS	Sophisticated
Item 10	9	11	2	13	R/LPK-WD	Proficient

Note: Items are in the order of decrease in calculated knowledge gain following the PPST's teaching

Table 8.4 suggests that there is largely a direct relationship between the learners' high post-test item performance and most of the sophisticated category eTSPCK episodes. The test-items where the learners show more knowledge gains can be linked to the teaching moments in which Noma displayed sophisticated eTSPCK episodes. For example, item 4 which was linked to a sophisticated eTSPCK episode (R/LPK/WD/CS) had a pre-and post-test item performance of 0 and 12 points respectively, resulting in a huge 80% of learners with a knowledge gain.

Additionally, the results suggest a direct relationship between sophisticated eTSPCK episodes that were found out of fit and the learners' highest performance in the post-test. For example, a high

number of the learners presented correct responses for items 6 and 7 (13 out of 15 learners) and 8 (12 out of 15 learners) in the post-test following Noma's teaching that revealed sophisticated eTSPCK episodes with at least one repeating TSPCK component.

Comparing Noma's eTSPCK episodes and the learners' performance for item 4

Item 4 required the learners to explain how a chemical reaction that has reached a state of Chemical Equilibrium reacts to any form of disturbance caused. The learners' understanding of this concept reflects their understanding of the application of the Le Chatelier's principle, a concept that the learners find difficult to comprehend. On teaching this concept, Noma exhibited a sophisticated eTSPCK episode, displaying an interaction between four TSPCK components.

Figure 8.3 presents an extract from Noma's teaching that displays a sophisticated episode.

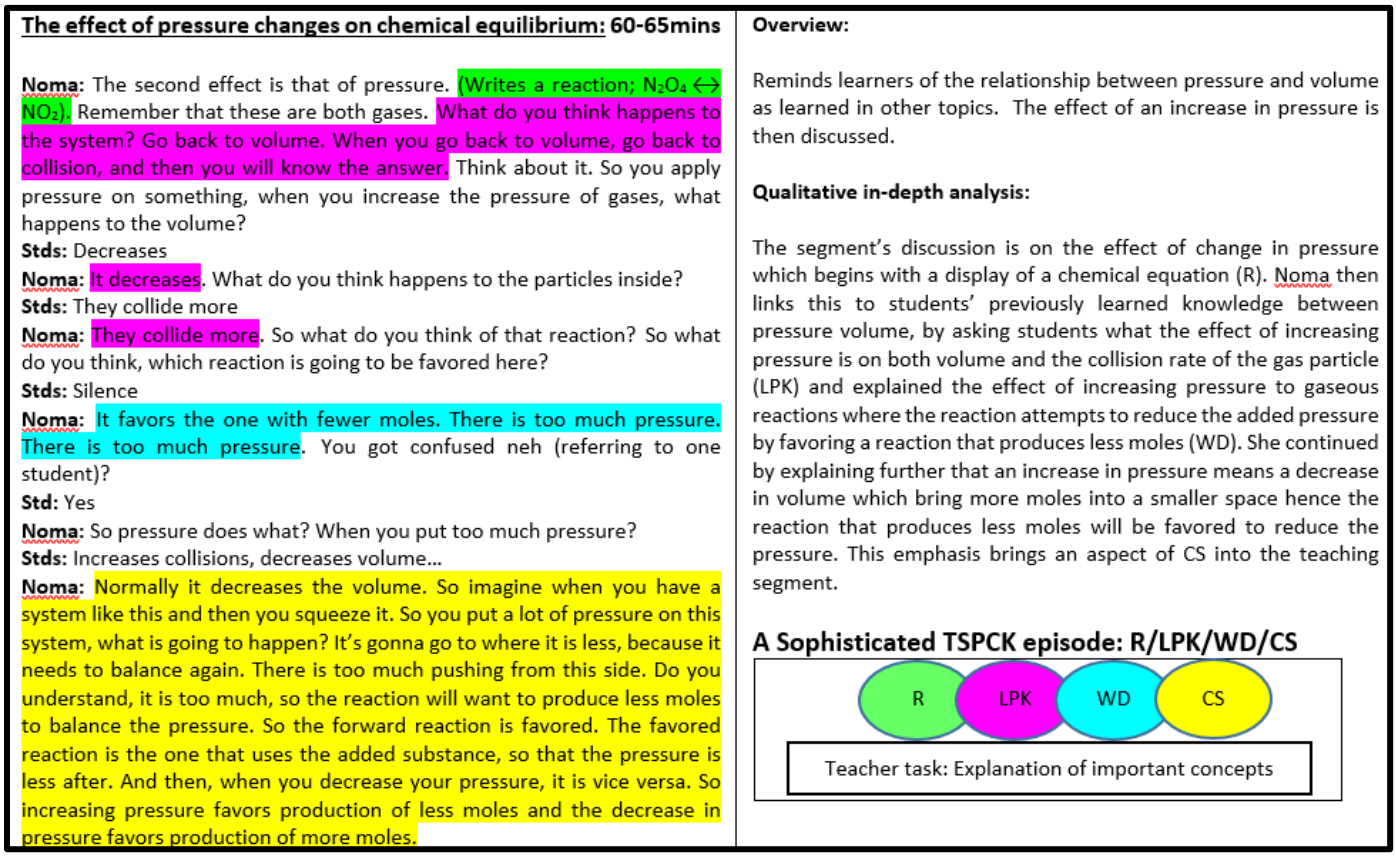


Figure 8. 3: Noma's teaching segment on the effect of a disturbance at Chemical Equilibrium

Using a symbolic chemical reaction (R), Noma used the learners' previously learned concept (LPK), volume versus pressure changes relationship, to explain the effect of increasing pressure. She further explained that a decrease in volume, which is similar to increasing the pressure causes

a reaction to favor one that produces less moles as an attempt to reduce the added pressure. The understanding of this concept is considered difficult for the learners (WD) while the emphasis made brought to the fore, an aspect of curricular saliency (CS), as Noma explained what is important. The explanation resulted into a sophisticated TSPCK episode, displaying an interaction between four different TSPCK components (R/LPK/WD/CS).

Presented in Figures 8.4 and 8.5 are the extracts from the responses of Noma's learners on the same concept represented as item 4 on the learner-achievement test. The pre- and post-test responses on the item are both followed by an analysis that compares the responses to Noma's teaching episode (Figure 8.3).

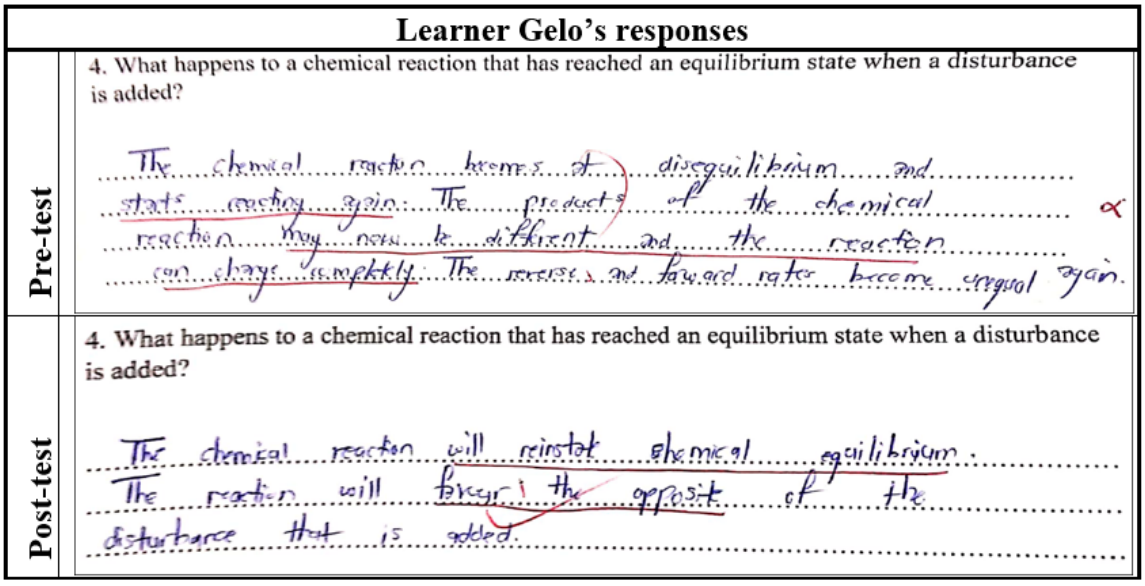


Figure 8. 4: Learner Gelo's written responses on item 4 of learners' achievement tests

Looking at a pre-test response by Gelo in Figure 8.4, the response shows lack of understanding or a confused understanding of what happens. This is observed in the response that Gelo gave that, "a reaction starts reacting again". This response projects a common learner misconception where the learners' understanding is that there is no reaction at Chemical Equilibrium. The post-test response shows an improved understanding of the concept as learner Gelo precisely shows that a reaction that opposes the added disturbance is favored and that a new equilibrium is eventually reinstated.

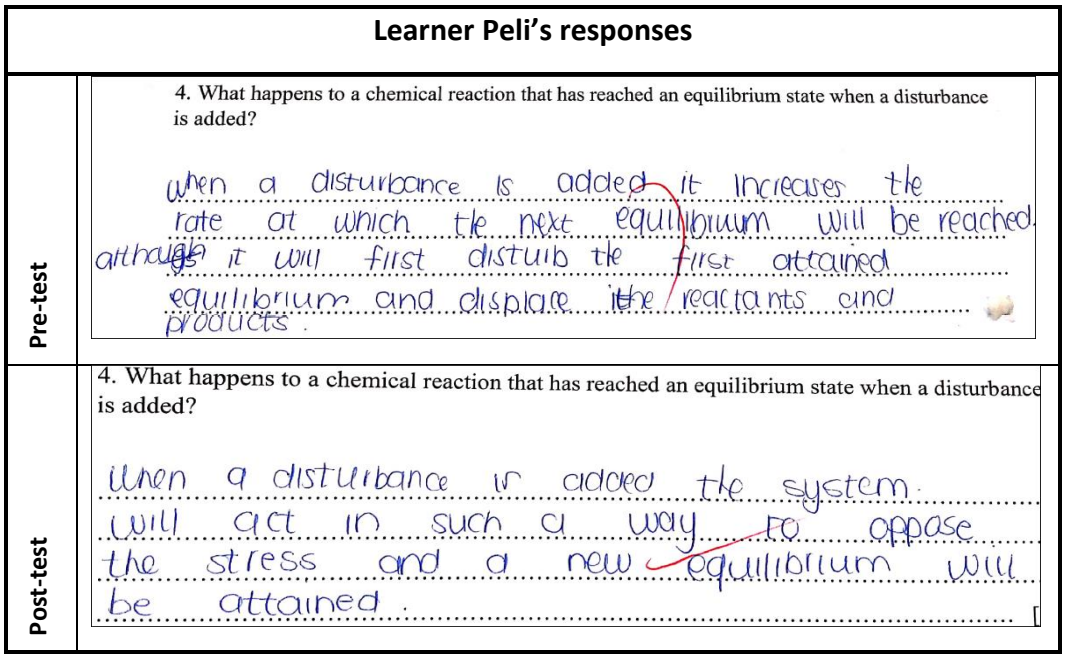


Figure 8. 5: Learner Peli written responses on item 4 of learners' achievement tests

As shown in Figure 8.5, learner Peli pre-test response does not show any understanding of the concept as Peli wrote that a disturbance added increases the rate at which the next equilibrium is formed. The response that Peli presented is false, as the rate of a reaction would be limited to specific forms of disturbance, either a change in the concentration of only the reactants and/or the temperature. The post-test response however, showed an improved understanding as Peli was able to indicate that a reaction that opposes the added disturbance/stress is favored and later a new Chemical Equilibrium position will be formed.

When the learners were asked what teacher actions, they found useful during the lessons in supporting their understanding of the concepts, the following responses were common to most learners: (i) the use of examples that the learners could relate to and (ii) the explicit emphasis made when explaining the concepts. For example, learner Gube wrote that Noma "*gave an everyday example that I do. That helped me to understand the concept, e.g., the boiling of water*". Put in different words was learner Felo's response that the PPST *"gave examples and linked them to everyday situations"*. The responses given by the learners is evident in the explanations given by Noma in episodes 2 and 3 which ran between 3-10 minutes and 10-17 minutes into the lesson (See Appendix R), where an example of water changing its phase is used as a scenario to help the learners to understand the concept of reversibility. Furthermore, the extract in Figure 8.3, presented the evidence of Noma's re-calling and building-on on the learners' prior knowledge of the

changing volume to introduce the concept of the effect of pressure changes at Chemical Equilibrium. Using what the learners can relate to is in line with the constructivist's theory of learning which contends that learning becomes more effective when it is connected to the existing knowledge (Kurnaz and Sağlam-Arslan, 2011). Additional views provided by the learners, were that the PPST *explained the concepts again and again to show emphasis and to make the learners understand*. This demonstrates the aspect of repeatability which the learners stated as contributing to their understanding. This can also be observed in the details that Noma gave repeatedly in figure 8.3 when she explained how an increase in pressure affected the state of equilibrium. An emphasis of important aspects brought forth by the repeat of the concept explanations takes curricular saliency (CS) into consideration.

The observed change in the understanding of Chemical Equilibrium concepts, as observed in the learners' post-item responses and performance, can be attributed to Noma's use of representations that were familiar to the learners, including the replicating explanations to help put emphasis on important concepts. This, according to the learners, is what contributed to their understanding of the concepts.

THE CASE OF LERATO AND HER LEARNERS

i) A quantitative analysis of the correlation between PPSTs' eTSPCK and learner performances

Lerato's teaching comprised 25 eTSPCK episodes as analyzed in Chapter 6. Table 8.5 displays the content covered per teaching segment, the eTSPCK episode category and the corresponding rubric score recalled from the analysis of Lerato's lesson done in Chapter 6. The last columns (columns C-6, C-7 and C-8) present the newly calculated eTSPCK episode Rasch person measures and the fit statistical parameters.

Table 8. 5: Lerato's eTSPCK episodes converted into Rasch person measures

C-1	C-2	C-3	C-4	C-5	C-6	C-7	C-8
Time (Mins)	Teaching Segment	Emerging Episodes	TSPCK Episode Category	TSPCK Rubric level	Rasch Person measures	*Fit statistics* IN. ZSTD	OUT. ZSTD
2-7	How reactions happen	R/CS/WD	Proficient	2	1.31	0.02	-0.07
7-10	Conditions for chemical reactions	R/CS	Basic	1	0.00	-1.49	-1.48
10-15	The activation energy	CS/R/LPK	Proficient	2	1.31	-0.35	-0.26
15-21	Open and closed systems	R/LPK-CS/WD/R/CS	Sophisticated	3	2.81	MAX	MAX
21-27	Evaluation: Types of systems	LPK-CS/R	Proficient	2	1.31	-0.35	-0.26
27-32	Reversible reactions	CS/R-CS/WD/LPK/CS	Sophisticated	3	2.81	MAX	MAX
32-37	Simulating reversible reactions	CS/R/CS	Proficient	2	0.00	-1.49	-1.48
37-41	Concentration time graph	R/CS/WD	Proficient	2	1.31	0.02	-0.07
41-43	Changes in rates of forward and reverse reaction	CS/R	Basic	1	0.00	-1.49	-1.48
43-50	Concentration time graph continued	LPK-R/CS/LPK	Sophisticated	3	1.31	1.33	1.54
50-55	Characteristics of CE and dynamic CE	WD/CS/LPK/R	Sophisticated	3	2.81	1.89	2.00
55-60	Conditions for CE	CS/WD	Basic	1	0.00	1.11	1.15
60-64	General lesson evaluation	LPK-CS	Basic	1	0.00	0.91	0.87
64-70	Rate time graph	LPK-R/CS	Proficient	2	1.31	-0.35	-0.26
70-77	Rate and concentration time graphs	LPK-CS/WD/R/CS	Sophisticated	3	2.81	MAX	MAX
77-80	Concentration time graph for the Haber process	LPK-R/CS	Proficient	2	1.31	-0.35	-0.26
80-87	Factors affecting CE: concentration	CS/WD/R	Proficient	2	1.31	0.02	-0.07
87-90	The spike after increasing concentration of a reagent	R/LPK/WD	Proficient	2	1.31	1.33	1.54
90-93	The effect of change in concentration	LPK/R/WD/LPK	Sophisticated	3	1.31	1.33	1.54
93-98	Changing pressure	LPK-CS/R/WD	Sophisticated	3	2.81	1.89	2.00
98-101	Balancing equations	LPK-CS/R	Proficient	2	1.31	-0.35	-0.26
101-102	A spike or lack of, after a disturbance	WD/R	Basic	1	0.00	1.11	1.15
102-110	Increasing temperature	LPK/CS/R/WD	Sophisticated	3	2.81	1.89	2.00
110-117	Summary on CE discussions	CS/R/LPK/R/WD	Sophisticated	3	2.81	MAX	MAX
117-120	The Le Chatelier's Principle	WD/CS	Basic	1	0.00	1.11	1.15
Reliability indices summarized	Rasch mean 1.36 Person reliability 0.00 Item reliability 0.80 Infit/Outfit indices 4 out of fit						

Note: LPK-Learner Prior Knowledge; CS-Curricular saliency; WD-What is difficult to teach or understand; R-Representations; CTS-Conceptual teaching strategies. The order in which episodes are presented is based on descending order of the Rasch person measures. The mean for item measure set to zero & Units per Logit=1 for the tests (UIMEAN=0 and USCALE=1)

Similar to Noma's case, the MAX fit statistics were revealed for sophisticated eTSPCK episodes with the highest person Rasch measures (2.81) consisting also of repeating TSPCK components. 4 such episodes were classified by the Rasch analysis model as out of fit, with features not common to most TSPCK components combinations.

Table 8.6 below presents Lerato's learners' pre-and post-achievement Rasch person measures recalled from Chapter 7.

Table 8. 6: Lerato's learners' Rasch person measures imported as Table 7.10 in Chapter 7

Learner code	Pre-learner achievement test			Post-learner achievement test		
	Rasch person measure	*Fit statistics*		Rasch person measure	*Fit statistics*	
		IN. ZSTD	OUT. ZSTD		IN. ZSTD	OUT. ZSTD
TOKA	1.23	1.01	0.66	2.40	0.99	0.67
DIWE	0.63	0.51	0.29	2.40	0.87	0.46
NALD	-0.50	1.86	2.05	2.40	-0.78	-0.41
SELO	-0.50	-0.90	-0.73	1.24	0.22	0.33
EMAN	-0.50	0.44	0.04	1.24	-0.34	-0.23
MPHO	-1.13	-0.71	-0.56	1.24	0.62	1.81
SILE	-1.13	-0.71	-0.56	1.24	-0.34	-0.23
TUME	-1.13	1.87	1.20	1.24	-0.71	-0.44
RABO	-1.13	-0.71	-0.56	0.37	0.36	-0.02
SEGO	-1.13	-1.09	-0.76	0.37	-0.95	-0.72
MANE	-1.90	-0.23	-0.15	0.37	0.36	-0.02
DEKA	-1.90	0.28	0.63	0.37	0.36	-0.02
MELI	-3.04	-0.81	-0.57	0.37	-0.95	-0.72
LIND	-3.04	-0.81	-0.57	-0.42	-1.45	-0.89
Reliability indices summarized	Rasch mean	-1.08		Rasch mean	1.06	
	Person reliability	0.60		Person reliability	0.73	
	Item reliability	0.73		Item reliability	0.83	
	Infit/Outfit indices	1 out of fit		Infit/Outfit indices	All within the +2;-2 range	

The names of the learners are presented in descending order of Rasch measures in the post-test. The mean for item measure set to zero & Units per Logit=1 for the tests (UIMEAN=0 and USCALE=1)

Similar to Noma's case, the Rasch person measures for Lerato's eTSPCK episode (displayed on Table 8.5) and the learners' Rasch person measures from Table 8.6 were put together on SPSS to calculate the Pearson correlation coefficient (*r*). Random sampling which was done in three batches was used to enable the pairing of all the variables. This was important to do since the numbers of variables differ and the calculation for correlation requires paired data sets. Figure 8.6 presents the correlation results obtained through the SPSS Software.

LERATO

Correlations

		Learners' Pre-Test Person measures	Batch 1: Lerato's Overall Episodes	Batch 2: Lerato's Overall Episodes	Batch 3: Lerato's Overall Episodes	Average	Learners' Post-Test Person measures	Batch 1: Lerato's Overall Episodes	Batch 2: Lerato's Overall Episodes	Batch 3: Lerato's Overall Episodes	Average
Lerato's Overall episodes	Pearson Correlation	1	-.066	-.294	-.156	-.172	1	.817	.768	.780	.788
	Sig. (2-tailed)		.823	.308	.670	.600		.045	.034	.010	.030
	N	14	14	14	14	14	14	14	14	14	14

Figure 8. 6: Lerato's overall eTSPCK episodes and his learners' Rasch Person measures

Figure 8.6 presents three batches of the Pearson correlation coefficients of r_1 = -0.066 (p = 0.823), r_2 = -0.294 (p = 0.308) and r_3 = -0.156 (p = 0.670) between Lerato's eTSPCK and the learners' pre-test performance calculated at a significant level α = 0.05. An average Pearson correlation coefficient of r = -0.172 (p = 0.600) was calculated between Lerato's eTSPCK episodes and the learners' pre-test performance. The strength and direction of the correlation coefficients (r), at the alpha values higher than the significant level of 0.05 for all the three batches, indicate the presence of a statistically insignificant and negligible correlation between Lerato's eTSPCK and the learners' performance. The calculated average Pearson correlation coefficient is below r = -0.30 which is the agreed cutoff value that classifies the correlations between two variables as negligible (Hinkle *et al*., 2003).

Furthermore, the Pearson correlation coefficients of r_1 = 0.817 (p= 0.045), r_2= 0.768 (p = 0.034) and r_3 = 0.780 (p = 0.010) at a significant level α = 0.05, were calculated between Lerato's eTSPCK and learner performances for the post-test. An average Pearson correlation coefficient of r = 0.788 (p = 0.03) was calculated between Lerato's eTSPCK episodes and the learners' post-test performance. The strength and direction of the resultant correlation coefficients for the three batches indicated the presence of a statistically significant and high correlation between Lerato's eTSPCK and the learners' performances in the post-test. The calculated average Pearson correlation coefficient (r = 0.788) is within the established cutoff range of r = **+(0.70 to 0.90)** which classifies the correlation as high.

(i) A qualitative analysis of the correlation between PPSTs' eTSPCK and learner performances.

As highlighted in section 8.1, Lerato's class had a total of 14 learner participants. The highest performance that could be displayed for the tests should correspond to the total number of correct

answers to each item in the pre-and post-test. Table 8.7 depicts the learners' pre- and post-achievement test item performance and the linking eTSPCK episodes from Lerato's teaching.

Table 8. 7: Lerato's eTSPCK episodes against his learners' conceptual performances

Test item	Lerato's learners' performances				Lerato's eTSPCK	
	Pre-test	*Post-test*	*Knowledge gain*	*Percentage gain (%)*	*TSPCK episode*	*TSPCK category*
Item 5	1	13	12	86	LPK-R/CS/LPK	Sophisticated
Item 7	2	14	12	86	R/LPK-CS/WD/R/CS	Sophisticated
Item 6	3	14	11	79	R/LPK-CS/WD/R/CS	Sophisticated
Item 9	3	13	10	71	WD/CS/LPK/R	Sophisticated
Item 11	0	9	9	64	WD/CS	Basic
Item 8	6	14	8	57	CS/R-CS/WD/LPK/CS	Sophisticated
Item 1	8	14	6	43	LPK-R/CS	Proficient
Item 10	5	9	4	29	CS/WD/R	Proficient
Item 2	5	8	3	21	WD/CS	Basic
Item 4	1	3	2	14	WD/CS	Basic
Item 3	10	12	2	14	LPK-R/CS/LPK	Sophisticated

Note: Items are in the order of decrease in the calculated knowledge gain following the PPST's teaching

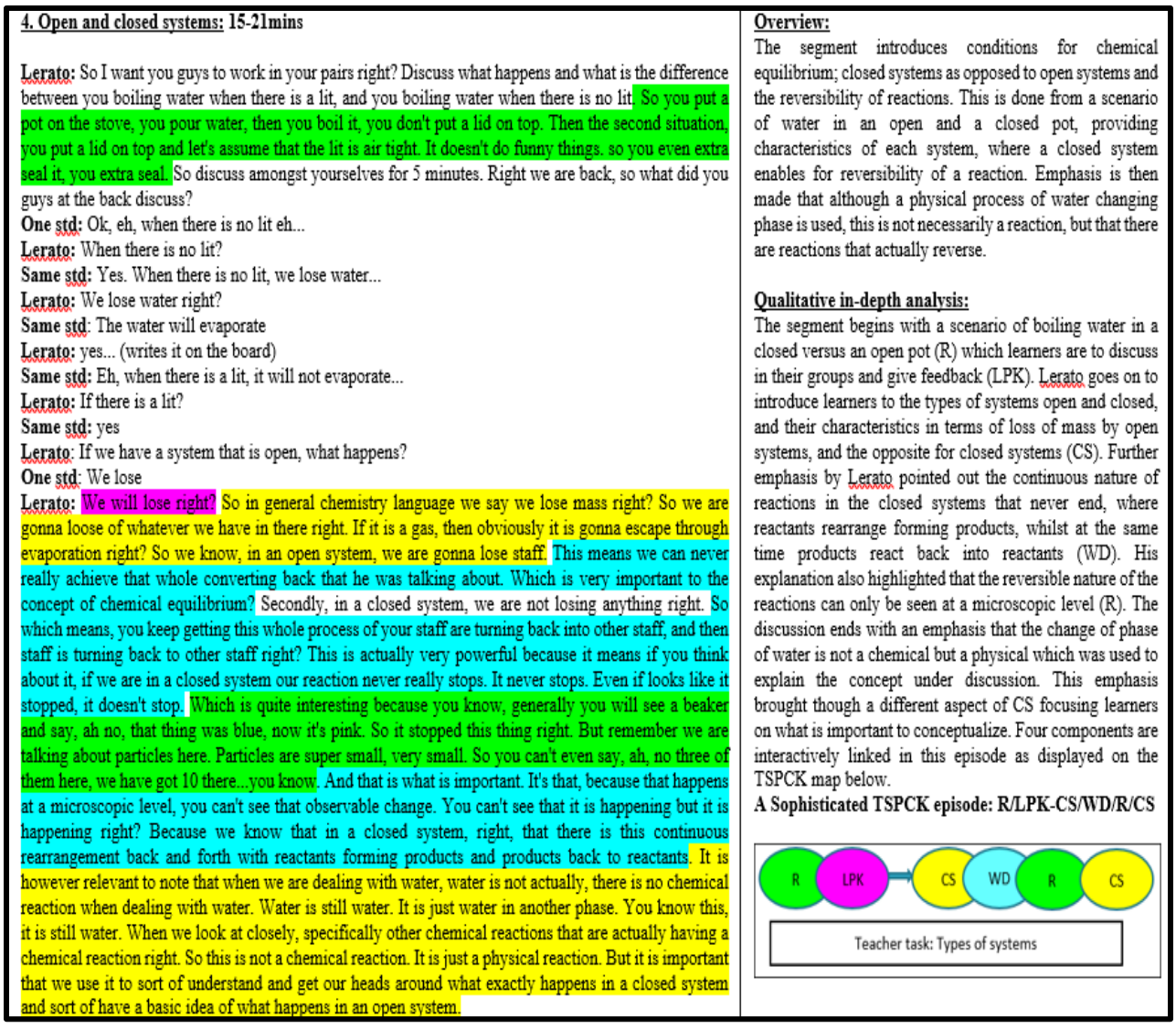
Table 8.7 suggests a direct relationship between the learners' high knowledge gains and higher eTSPCK episode categories, just as it is the pattern in Noma's case. For example, an 86% of learners showing knowledge gain is observed for item 7 from a pre-test score of 2 after a teaching that exhibited a sophisticated TSPCK episode (R/LPK-CS/WD/R/CS).

Additionally, the results suggest a direct relationship between sophisticated eTSPCK episodes that were found out of fit and the learners' highest performances in the post-test. For example, all 14 learners presented correct responses for items 6,7 and 8 in the post-test, following Lerato's teaching that revealed sophisticated eTSPCK episodes with at least one repeating TSPCK component.

The analysis of Lerato's eTSPCK episodes and learner responses on item 7

Table 8.9 presents an extract of Lerato's eTSPCK episode displaying his teaching on the types of chemical reaction systems. Lerato's explanation of this concept occurred between 15-21 minutes into the lesson. Following this was a discussion on reversible reactions, another essential condition needed for a chemical reaction to reach a state of Chemical Equilibrium. Lerato used a simulation video to put emphasis and visualization of the simultaneous nature of a forward and a reverse

reaction, as long as the system remains closed to avoid the loss of mass. This resulted into a sophisticated TSPCK episode (CS/R-CS/WD/LPK/CS). Figure 8.7 presents an extract from Lerato's teaching episode where he provided explanations on the types of systems.



4. Open and closed systems: 15-21mins

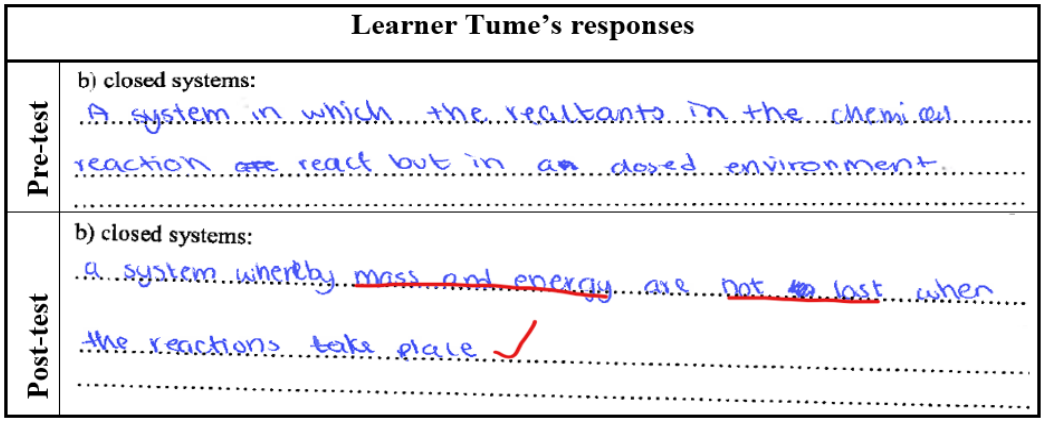
Lerato: So I want you guys to work in your pairs right? Discuss what happens and what is the difference between you boiling water when there is a lit, and you boiling water when there is no lit. So you put a pot on the stove, you pour water, then you boil it, you don't put a lid on top. Then the second situation, you put a lid on top and let's assume that the lit is air tight. It doesn't do funny things. so you even extra seal it, you extra seal. So discuss amongst yourselves for 5 minutes. Right we are back, so what did you guys at the back discuss?
One std: Ok, eh, when there is no lit eh...
Lerato: When there is no lit?
Same std: Yes. When there is no lit, we lose water...
Lerato: We lose water right?
Same std: The water will evaporate
Lerato: yes... (writes it on the board)
Same std: Eh, when there is a lit, it will not evaporate...
Lerato: If there is a lit?
Same std: yes
Lerato: If we have a system that is open, what happens?
One std: We lose
Lerato: We will lose right? So in general chemistry language we say we lose mass right? So we are gonna loose of whatever we have in there right. If it is a gas, then obviously it is gonna escape through evaporation right? So we know, in an open system, we are gonna lose staff. This means we can never really achieve that whole converting back that he was talking about. Which is very important to the concept of chemical equilibrium? Secondly, in a closed system, we are not losing anything right. So which means, you keep getting this whole process of your staff are turning back into other staff, and then staff is turning back to other staff right? This is actually very powerful because it means if you think about it, if we are in a closed system our reaction never really stops. It never stops. Even if looks like it stopped, it doesn't stop. Which is quite interesting because you know, generally you will see a beaker and say, ah no, that thing was blue, now it's pink. So it stopped this thing right. But remember we are talking about particles here. Particles are super small, very small. So you can't even say, ah, no three of them here, we have got 10 there...you know. And that is what is important. It's that, because that happens at a microscopic level, you can't see that observable change. You can't see that it is happening but it is happening right? Because we know that in a closed system, right, that there is this continuous rearrangement back and forth with reactants forming products and products back to reactants. It is however relevant to note that when we are dealing with water, water is not actually, there is no chemical reaction when dealing with water. Water is still water. It is just water in another phase. You know this, it is still water. When we look at closely, specifically other chemical reactions that are actually having a chemical reaction right. So this is not a chemical reaction. It is just a physical reaction. But it is important that we use it to sort of understand and get our heads around what exactly happens in a closed system and sort of have a basic idea of what happens in an open system.

Overview:
The segment introduces conditions for chemical equilibrium; closed systems as opposed to open systems and the reversibility of reactions. This is done from a scenario of water in an open and a closed pot, providing characteristics of each system, where a closed system enables for reversibility of a reaction. Emphasis is then made that although a physical process of water changing phase is used, this is not necessarily a reaction, but that there are reactions that actually reverse.

Qualitative in-depth analysis:
The segment begins with a scenario of boiling water in a closed versus an open pot (R) which learners are to discuss in their groups and give feedback (LPK). Lerato goes on to introduce learners to the types of systems open and closed, and their characteristics in terms of loss of mass by open systems, and the opposite for closed systems (CS). Further emphasis by Lerato pointed out the continuous nature of reactions in the closed systems that never end, where reactants rearrange forming products, whilst at the same time products react back into reactants (WD). His explanation also highlighted that the reversible nature of the reactions can only be seen at a microscopic level (R). The discussion ends with an emphasis that the change of phase of water is not a chemical but a physical which was used to explain the concept under discussion. This emphasis brought though a different aspect of CS focusing learners on what is important to conceptualize. Four components are interactively linked in this episode as displayed on the TSPCK map below.
A Sophisticated TSPCK episode: R/LPK-CS/WD/R/CS

Figure 8. 7: Lerato's teaching segment on different types of systems

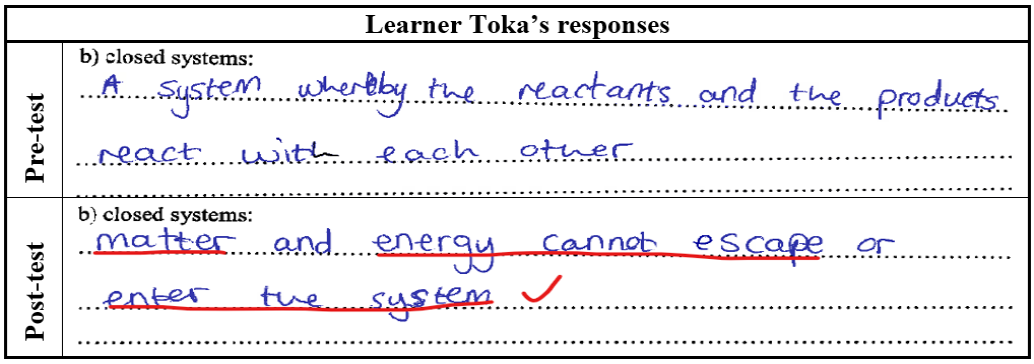
Figure 8.8 portrays Lerato's learner's written responses (learner Tume) before and after the teaching on the different types of systems. Item 7 required the learners to provide their understanding of what closed systems are.



Learner Tume's responses	
Pre-test	b) closed systems: A system in which the reactants in the chemical reaction ~~are~~ react but in a closed environment.
Post-test	b) closed systems: A system whereby mass and energy are not lost when the reactions take place ✓

Figure 8. 8: Learner Tume's written responses on item 7 of the learners' achievement tests

As shown in the pre-test response written by Tume in Figure 8.8 the learner showed a minimal understanding of what closed systems are, as he indicated that the reaction happens in a "closed environment" which is correct, however, the learner did not provide any explanation of what the characteristics of a closed environment are. The understanding was observed to have improved in the post-test response as Tume wrote a rich response on closed systems, explicitly citing the important features of the system. A similar understanding of the concept was portrayed in Toka's responses as presented in Figure 8.9 below.



Learner Toka's responses	
Pre-test	b) closed systems: A system whereby the reactants and the products react with each other
Post-test	b) closed systems: matter and energy cannot escape or enter the system ✓

Figure 8. 9: Learner Toka's written responses on item 7 of learners' achievement tests

As shown in the pre-test response by Toka in Figure 8.9, unlike learner Tume, the learner revealed no understanding of closed systems. The response following Lerato's teaching showed an improved understanding. Toka wrote that these are the type of systems in which matter, and energy are not lost.

On the question of what teacher actions supported their understanding of the concepts during the lessons the learners cited (i) the use of examples and diagrams and (ii) the use of the examples that

relate to the learners' real-life experiences. Observed from learner Keka's response, the learner wrote that teacher-Lerato *"used examples, diagrams and graphs"* which assisted their understanding of the concepts. This is in line with what Mitchell and colleagues attested to, that the use of representations (R) when teaching facilitates the learners' conceptual understanding by enabling the learners to make sense of the concept being discussed (Mitchell *et. al.,* 2014). The use of diagrams which came in the form of a simulation is observed throughout most parts of Lerato's teaching (see Appendix S). The simulation which was used to explain the concept of reversibility was also used after an introduction of the types of systems where a scenario of a cyclic process of the water changing phase from liquid to gas and back to liquid was given as an example. Responding to the same question, learner Sile presented that the PPST *"gave life examples and interpreted what I had an idea on to further explain and clarify the concept"*. The use of a scenario of water changing phase also meant that Lerato considered the existing knowledge that the learners bring into the classroom (LPK), which could affect their understanding of the current topic content (Kurnaz & Sağlam-Arslan, 2011). With respect to the use of graphs, following the explanation of reversibility (episode 27-32), Lerato was observed (in multiple teaching segments) explaining the concept of reversibility using concentration and rate versus time graphs (see Appendix S). According to the learners, this also contributed to their understanding of the topic concepts.

It can be concluded that the use of diagrams and graphs as representations by Lerato, has contributed to the learners' comprehension of Chemical equilibrium concepts. The learners suggest that using examples that are familiar and associated with their everyday experiences heightens the understanding of the concepts.

THE CASE OF SARA AND HER LEARNERS

- **A quantitative analysis of the correlation between PPSTs' eTSPCK and learner performance.**

As analyzed in Chapter 6, Sara's teaching comprised 26 eTSPCK episodes. Presented on Table 8.8 is the content covered per teaching segment by Sara, including the eTSPCK episode categories and the awarded rubric scores all recalled from the analysis done in Chapter 6. Additional information of Sara's newly calculated eTSPCK episodes Rasch person measures and the fit statistical parameters are displayed from columns C-6, C-7 and C-8.

Table 8. 8: Sara's eTSPCK episodes converted into Rasch person measures

C-1	C-2	C-3	C-4	C-5	C-6	C-7	C-8
Time (min)	Teaching segment	Emerging episode	TSPCK Episode Category	TSPCK Rubric level	Rasch Person Measure	*Fit statistics* IN. ZSTD	OUT. ZSTD
4-10	Lesson objectives	CS/LPK	Basic	1	-0.92	-0.58	0.17
10-13	Irreversible reactions	LPK/R/CS/R	Sophisticated	3	2.22	-0.39	-0.09
13-18	Reversible reactions	CS/LPK/R/LPK/WD	Sophisticated	3	2.22	-0.62	-0.72
18-19	Closed systems	CS/LPK	Basic	1	-0.92	-0.58	0.17
19-22	Concentration time graph	R/LPK/WD	Proficient	2	0.23	0.23	0.35
22-26	Dynamic Chemical Equilibrium (CE)	WD/R/LPK/CS	Sophisticated	3	2.22	0.23	0.35
26-31	Rate time graph	LPK/CS-R/WD	Sophisticated	3	2.22	-0.62	-0.72
31-40	Characteristics of CE	LPK/WD-R/LPK	Sophisticated	3	2.22	0.14	0.17
40-43	Conditions for CE	LPK/R/WD/CS	Sophisticated	3	2.22	-0.62	-0.72
43-44	Reversible & irreversible reactions	LPK/R/WD	Proficient	2	0.23	0.14	0.17
44-46	Definition of CE	CS/WD/LPK	Proficient	2	0.23	0.36	0.31
46-48	CE explained using graphs	R/CS	Basic	1	-0.92	0.98	0.52
48-55	Calculating rate	LPK-R/CS	Proficient	2	0.23	-0.39	-0.09
55-60	Rate change in concentrations over time	LPK/R/CS	Proficient	2	0.23	-0.39	-0.09
60-65	Forward and backward reactions	LPK/R/CS/LPK	Sophisticated	3	2.22	-0.39	-0.09
65-69	Evaluation: Dynamic CE	LPK/WD	Basic	1	-0.92	0.23	0.35
69-72	Meaning of Dynamic	LPK-R/WD	Proficient	2	0.23	0.14	0.17
72-76	Change in concentrations before CE	LPK-R/CS	Proficient	2	0.23	-0.39	-0.09
76-84	Change in rate of forward reaction until CE	LPK-R/CTS/CS	Sophisticated	3	2.22	1.92	1.48
84-89	Change in rate of reverse reaction until CE	LPK-R/WD/CS	Sophisticated	3	2.22	-0.62	-0.72
89-96	Factors affecting CE (Le Chatelier's Principle)	CS/WD/LPK/CS	Sophisticated	3	2.22	-0.62	-0.72
96-103	Increase in Concentration of a reactant	CS/WD-CS/R/CTS	Sophisticated	3	2.22	2.00	1.35
103-107	Increase in Concentration of a product	LPK-R/WD	Proficient	2	0.23	0.14	0.17
107-111	Decrease in Concentration of a reactant	LPK-WD/R/CS	Sophisticated	3	2.22	-0.62	-0.72
111-115	Decrease in Concentration of a product	LPK/WD-CS/R	Sophisticated	3	2.22	-0.62	-0.72
117-120	Effect of a disturbance: Concentration time graph	R/CS-WD	Proficient	2	0.23	0.88	1.00

Reliability indices summarized	
Rasch mean	0.65
Person reliability	0.00
Item reliability	0.90
Infit/Outfit indices	All within the +2;-2 range

Note: LPK-Learner Prior Knowledge; CS-Curricular saliency; WD-What is difficult to teach or understand; R-Representations; CTS-Conceptual teaching strategies. The order in which episodes are presented is based on descending order of the Rasch person measures. The mean for item measure set to zero & Units per Logit=1 for the tests (UIMEAN=0 and USCALE=1)

Unlike in Noma and Lerato's cases, all the statistical fit values in Sara's case are within a range of -2 and +2 (Boone *et al*., 2014). Even in the cases where combinations of TSPCK components included components that were repeating in a single eTSPCK episode, none were marked as out of fit. As highlighted in blue in Table 8.8 above, Sara's lesson consisted of a higher number of such eTSPCK episodes, making this a conventional (and not questionable) combination.

Table 8.9 displays pre-and post-achievement test Rasch person measures (recalled from the analysis done in Chapter 7) of Sara's learners.

Table 8. 9: Sara's learners' Rasch person measures imported as Table 7.15 in Chapter 7

Learner code	Pre-learner achievement test			Post-learner achievement test		
	Rasch person measure	*Fit statistics*		Rasch person measure	*Fit statistics*	
		IN. ZSTD	OUT. ZSTD		IN. ZSTD	OUT. ZSTD
KAMO	-2.44	1.30	1.17	2.44	-0.70	-0.43
MBIZ	-0.08	-1.01	-0.66	2.44	-0.70	-0.43
MAEK	2.51	-0.83	-0.37	2.44	0.84	0.53
BUKA	-1.18	-1.34	-0.24	2.44	0.68	0.27
KALO	-0.08	-0.18	-0.27	2.44	0.84	0.53
LERA	-2.44	1.11	0.72	1.34	-0.44	-0.56
ZIMA	-0.08	-1.01	0.66	1.34	-0.89	-0.89
TATO	-2.44	1.11	0.72	1.34	-0.06	-0.12
KEKA	-1.18	-1.34	-0.24	1.34	0.27	0.77
TEKO	2.51	-0.83	-0.37	1.34	1.23	1.20
TEBO	-1.18	-1.34	-0.24	0.57	0.70	0.52
LESO	-0.08	-1.01	-0.66	0.57	-0.01	0.01
Reliability indices summarized	Rasch mean	-0.29		Rasch mean	1.67	
	Person reliability	0.61		Person reliability	0.73	
	Item reliability	0.80		Item reliability	0.86	
	Infit/Outfit indices	All within +2;-2 range		Infit/Outfit indices	All within +2;-2 range	

Note: The order in which learners are presented is based on descending order of Rasch measures in the post-test. The mean for item measure set to zero and Units per Logit=1 for the pre-and post-test (UIMEAN=0 and USCALE=1)

Similar to Noma and Lerato's cases, the Rasch person measures for Sara's eTSPCK episodes (see Table 8.8) and her learners' Rasch measures from Table 8.9 were together put on SPSS to calculate the Pearson correlation coefficient (r). Random sampling which was done in three batches was used to allow for the pairing of all the variables. Figure 8.10 depicts the correlation results.

SARA

Correlations

		Learners' Pre-Test Person measures	Batch 1: Sara's Overall Episodes	Batch 2: Sara's Overall Episodes	Batch 3: Sara's Overall Episodes	Average	Learners' Post-Test Person measures	Batch 1: Sara's Overall Episodes	Batch 2: Sara's Overall Episodes	Batch 3: Sara's Overall Episodes	Average
Sara's Overall Episodes	Pearson Correlation	1	-.029	-.285	-.307	-.207	1	.871	.856	.816	.841
	Sig. (2-tailed)		.930	.297	.333	.520		.010	.015	.013	.013
	N	12	12	12	12	12	12	12	12	12	12

Figure 8. 10: Sara's overall eTSPCK episodes and her learners' Rasch Person measures

The results in Figure 8.10 show the three batches of Pearson correlation coefficients of r_1 = -0.029 (p = 0.930), r_2 = -0.285 (p = 0.297) and r_3 = -0.307 (p = 0.333) between Sara's eTSPCK episode Rasch measures and learner performance calculated at a significant level α = 0.05. An average Pearson correlation coefficient of r = -0.207 (p = 0.52) was calculated between Sara's eTSPCK episodes and the learners' pre-test performance. The resultant strength and direction of the correlation coefficients (r), at the alpha values higher than the significant level of 0.05, suggest an insignificant negative negligible correlation between Sara's eTSPCK and the learners' performance in the pre-test. The calculated average Pearson correlation coefficient is below r = -0.30 which is the agreed cutoff for the correlations classified as negligible (Hinkle *et al*., 2003).

The Pearson correlation coefficients of r_1 = 0.871 (p = 0.010), r_2= 0.856 (p = 0.015) and r_3 = 0.816 (p = 0.013), at a significant level α = 0.05 were calculated for correlation between Sara's eTSPCK and learners' performance in the post-test. An average Pearson correlation coefficient of r = 0.841 (p = 0.013) was calculated between Sara's eTSPCK episodes and the learners' post-test performance. The strength and direction of the correlation coefficients (r), at the alpha values that are much lower than a significant level of 0.05, suggested an existence of a significant positive high correlation between Sara's eTSPCK and the learners' post-test performance. The calculated average Pearson correlation coefficient (r = 0.841) is within the established cutoff range of r = **+(0.70 to 0.90)** which classifies the correlation between two variables as high.

- **A qualitative analysis of the correlation between PPSTs' eTSPCK and learner performance**

As alluded to in section 8.1, Sara had a total of 14 learners in her class, two of whom did not write the pre-learner achievement test. This reduced the number to 12. As such, the highest performance that could be displayed for the tests should correspond to the total number of correct scores to each

item in the pre-and post-test. Table 8.10 presents the learners' pre and post-test item performance, and Sara's eTSPCK episodes linking directly to the test-items.

Table 8. 10: Sara's eTSPCK episodes against her learners' conceptual performance

Test item	Sara's learners' performances				Sara's TSPCK	
	Pre-test	*Post-test*	*Knowledge gain*	*Percentage gain (%)*	*TSPCK episode*	*TSPCK category*
Item 4	0	11	11	92	CS/WD/LPK/CS	Sophisticated
Item 9	0	11	11	92	WD/R/LPK/CS	Sophisticated
Item 11	0	8	8	67	CS/WD/LPK/CS	Sophisticated
Item 7	3	9	6	50	CS/LPK	Basic
Item 6	5	11	6	50	CS/LPK	Basic
Item 2	6	10	4	33	CS/WD/LPK/CS	Sophisticated
Item 8	9	12	3	25	CS/LPK/R/LPK/WD	Sophisticated
Item 10	8	11	3	25	LPK-R/WD	Proficient
Item 1	9	12	3	25	LPK/CS-R/WD	Sophisticated
Item 3	9	12	3	25	R/LPK/WD	Proficient
Item 5	2	4	2	17	R/LPK/WD	Proficient

Note: Items are in the order of decrease in calculated knowledge gain following the PPST's teaching

Table 8.10 suggests a relationship between the learners' highest knowledge gains and sophisticated eTSPCK episodes category. For example, items 4 and 9 had a knowledge gain of 92% with learner performance increasing from 0 to 11 in the pre-and post-test, respectively. The items were both linked to sophisticated eTSPCK episodes (CS/WD/LPK/CS) for item 4 and (WD/R/LPK/CS) for item 9. A detailed analysis of Sara's teaching of content related to item 9and accompanied by learner responses on the item is made below.

Also evident is that between 10 to 12 learners responded correctly to items related to sophisticated eTSPCK episodes that consisted of at least one TSPCK component repeating. Examples of such items, as presented in Table 8.10, include items 2, 4 and 8. A more complex eTSPCK episode CS/LPK/R/LPK/WD which related to item 8 had all the learners presenting a correct response in the post-test following Sara's teaching.

The analysis of Sara's eTSPCK episodes and learner responses on item 9

The teaching segment in which Sara discussed the dynamic nature of Chemical Equilibrium was identified between times 22-26 minutes into the lesson. Prior to this, Sara introduced the learners to concentration time graphs in order to explain the change in concentrations of reagents until

Chemical Equilibrium is achieved. Emphasis was made on the constant nature of concentrations of reactants and products at Chemical Equilibrium, which lead to her mentioning of the term "Dynamic Equilibrium". She further connected this chemical state to the reason for the occurrence of the common misconception of thinking that there is no reaction happening at that point. Her specific explanation unveiled a 3-component proficient eTSPCK episode (R/LPK/WD). Figure 8.11 presents the above-mentioned Sara's teaching segment on dynamic Chemical Equilibrium.

Explaining the dynamic nature of chemical equilibrium: 22-26mins

Sara: Let me explain why you can't see anything. So when we talk about chemical equilibrium, I said that you can't see what's taking place neh. This is because at a macroscopic...here is another terminology; what is macroscopic?
Stds: you can only see with a microscope?
Stds: We can't see with our own eyes
Sara: Microscopic, we cannot see with our naked eyes... So as I was trying to explain, when chemical equilibrium is established, sometimes it can still be that you can't see what is happening, or it appears as if there is nothing happening within this reaction. It seems as the reaction has gone to completion. But, at a microscopic level, there is something that is taking place. Typical example will be this (referring to a closed bottle with water). This is what system?
Stds: Closed
Sara: It's a closed system. So matter and what?



Stds: energy
Sara: Cannot...
Stds: leave or enter the system
Sara: Leave or enter the system. Say this water is in chemical equilibrium, how can you see that it is ok, how can you explain that it is chemical equilibrium?
One std: No reaction is occurring...
Sara: It is in chemical equilibrium?
Another std: There is no reaction happening... (misconception)
Sara: There is a reaction occurring. That's what I wanted to get at.
Stds: Oooh...
Sara: At a macroscopic level, it seems as if there is nothing happening like we said. But if we were to look deeper, if we had eyes that could see at the macroscopic level, there would be a reaction taking place... So when we are dealing with water… So I said H2O changes from liquid to gas. I can see this at a macroscopic level, at a microscopic level, I'm sorry. At a microscopic level. How do I see this? This bottle of mine has water in liquid form. But you can see at the top, there is like fuzzy things that you can see. So water evaporates. It goes up. And then when it evaporates, what form does it change to? The phase?
Stds: gas
Sara: It goes to a gaseous phase. And then it does return, it does…. you can see here, there are some droplets that we can see. These represent what, condensation. So there is evaporation that is taking place as the water goes up into the gaseous phase. And then there is a time, as this reaction is taking place...so I put this water in the morning, it was just liquid. Ok it was just liquid at the bottom. As time went by...evaporation occurred, but not all of it evaporates neh? So there comes a point in time whereby there is a lot of gaseous phase water in the system. The gaseous water particles then collide to form liquid phase. It goes from the gases phase, to the liquid phase, back to the liquid phase. It changes phase and the liquid that is in there, some of it again evaporates and form water in the gaseous phase...so it continues to occur. This is a classic example of phase change that is in equilibrium. So it is a phase change because we are changing from...
Stds: Liquid to gas...
Sara: And gas...
Stds: To liquid...
Sara: But it is also a phase change because we have liquid going to gases phase. That's what I wanted to get at. So at dynamic equilibrium, the Rate of forward and reverse reactions are continuously occurring at the same rate.

Overview:

Sara explains the dynamic nature of chemical equilibrium using a bottle containing water to demonstrate the simultaneous change of phase.

Qualitative in-depth analysis:

To explain the dynamic nature of chemical equilibrium; a difficult concept for students (WD), Sara pointed out that although at a macroscopic level it may appear as if the reaction has stopped, the reaction is actually still happening. She refers students to a bottle of water which she uses to explain how both evaporation and condensation continuously happen in a bottle. This is an example of a macroscopic representation (R). Through question an answer, Sara points out to the students that the bottle is closed and hence cannot allow matter in or out of the system. This could be her way of emphasizing on a condition that will allow for reversibility to occur, and hence chemical dynamic equilibrium. As the discussion progresses, some learners express a misconception by indicating that there is no reaction at equilibrium, which is another form of learner prior knowledge (LPK). Sara indicates that there is still a reaction happening, and argued further to eradicate this misconception, by explaining to students how water in a bottle changed phase through evaporation and condensation that happen at the same time within the system (CS).

This teaching segment displays an interaction between four components of TSPCK, with two of those components repeating. These are displayed in a TSPCK map below;

A sophisticated TSPCK episode displaying interwoven components: WD/R/LPK/CS

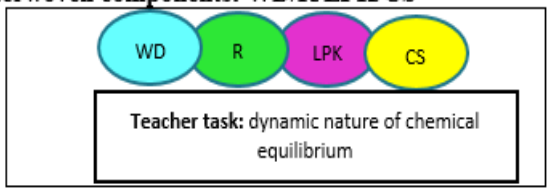


Figure 8. 11: Sara's teaching segment on dynamic Chemical Equilibrium

The written responses of Sara's learners on item 9 for both the pre-and post-learner achievement tests are presented in Figures 8.12 and 8.13. The analysis begins with learner Maek's written responses.

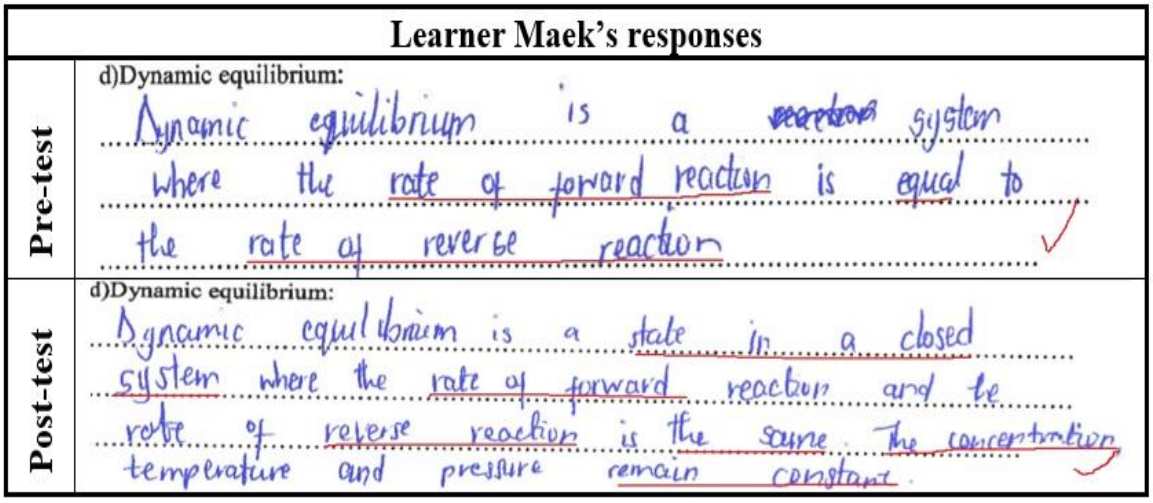


Figure 8. 12: Sara's learners' written responses on item 9 of learners' achievement tests

The pre-test response by learner Maek in Figure 8.12 shows some understanding of the concept of dynamic equilibrium as the learner correctly indicates that both the "rate of forward and reverse reactions" are equal dynamic equilibrium. Although learner Maek went into the classroom with some understanding of this concept, his conception of dynamic equilibrium was enriched following Sara's teaching. An improved understanding is observed in the post-response where Maek added that the factors such as concentration, temperature and pressure remain constant at dynamic Chemical Equilibrium. Maek's slight slip into mentioning that the 'concentrations remain constant' instead of specifying explicitly that it is the rate of change of the concentration of the reagents that remains constant is a bit worrying, but he was given the benefit of the doubt as he did not say they are the 'same'; that would have been a misconception. A similar understanding of the concept is observed in learner Tato's response presented in Figure 8.13.

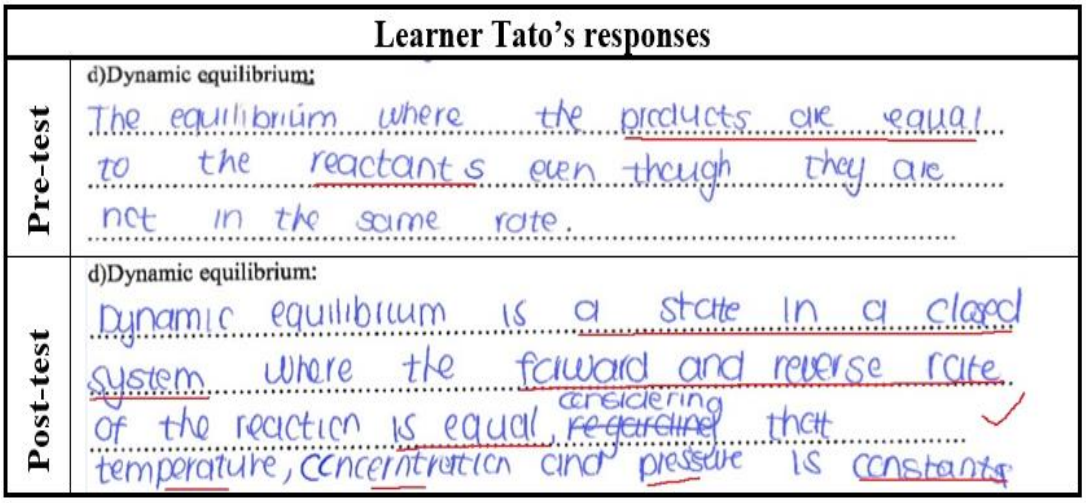


Figure 8. 13: The written responses of Sara's learners on item 9 of the learners' achievement tests

As shown from Figure 8.13, in the pre-test learner Tato revealed a misunderstanding related to the common learner misconception regarding the concentrations of reactants and products at equilibrium. This is observed in the statement that the learner made that "the products are equal to the reactants" which could infer to her thinking that the concentrations of reagents are equal at equilibrium. In contrast to the pre-test response, a thoughtful and precise explanation is provided in the post-test item as learner Tato showed that rates are equal, whilst all other elements, including concentration are kept constant. Similar to Maek's response in the post-test, it would have been more comforting if they had referred to the rate of change of the concentrations remaining constant than the concentrations themselves. This may also be a language issue as the learners use English as a second language.

When the learners were asked what tasks from their teachers' lessons helped them to understand the topic concepts, the learners enlisted: (i) the use of diagrams, graphs, (ii) slides with clear explanations and (iii) examples that relate to the learners' everyday experiences as the factors that contributed to their understanding. Seen from learner Maek's response, "[the teacher- Sara] *used diagrams and slides with explanations"* to explain concepts. Learner Kalo added to this by showing that Sara *"used graphs and physical examples of how a reaction happens"*. The use of these representations (R) strengthened the learners' understanding of Chemical Equilibrium concepts. The use of slides which projected diagrams and or graphs to explain the concepts were evident throughout Sara's lesson (see Chapter 6). Each slide also provided the learners with a

summary of the concept being discussed. The explanations of concepts depicted on the slides take into consideration an aspect of Curricular Saliency (CS), as they project the concepts that are important for the learners to understand the topic. A concept of dynamic equilibrium is considered by the learners as difficult to conceptualize because the reactions in the laboratory usually occur at a macroscopic level, preventing the learners from seeing the particles movement at a microscopic level. The learners also struggle to understand that the reactions occur simultaneously. In Table 8.13, Sara is observed explaining the concept using the cyclic and continuous notion of water changing phase. According to Sara's learners, using examples that are familiar assisted them with an understanding of the concepts. Put in own words, learner Keka indicated that "[The teacher- Sara] *used real life scenarios that are related to the topic"* and this heightened her understanding. This takes into consideration the aspect of LPK.

It can be concluded that, the use of slides with clear explanations, the use of diagrams and graphs, including the examples that the learners are accustomed to, were considered by the learners as the factors that contributed to their understanding of Chemical Equilibrium concepts.

8.3. Summary of key the findings in this Chapter

Four salient features were revealed through this analysis chapter. Firstly, while the lessons delivered by all the three PPSTs contained teaching segments that portrayed eTSPCK episodes that fall in all of the three levels (Figure 8.14) in the eTSPCK rubric, sophisticated eTSPCK episodes were in the majority in Sara's teaching.

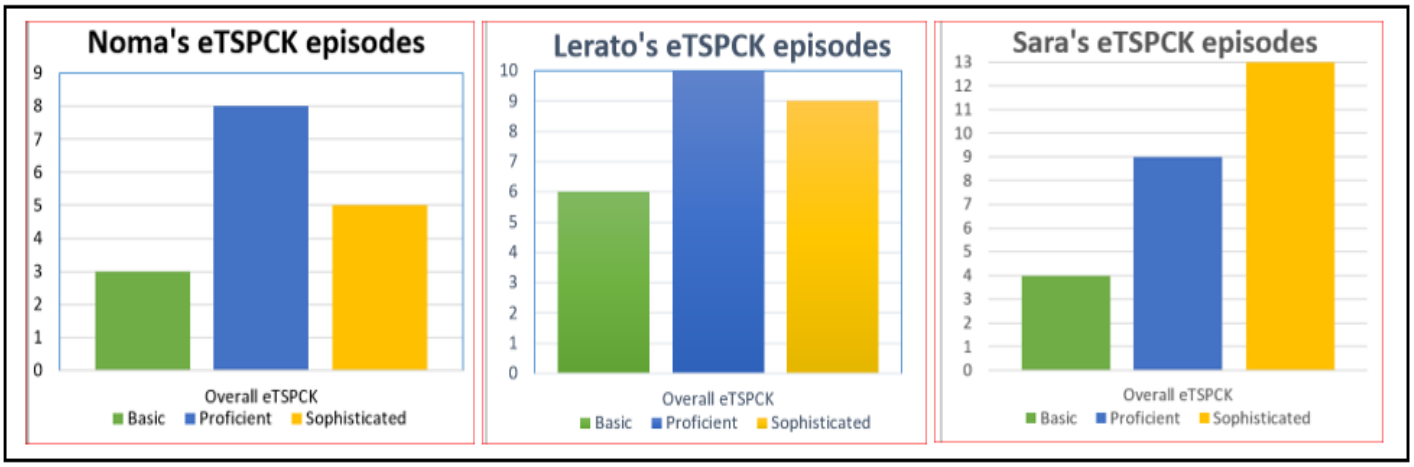


Figure 8. 14: Overall eTSPCK episodes identified from the PPSTs' teachings

The sophisticated eTSPCK corresponded to the huge, noticeable, positive jumps across the learners' pre- and post-tests, as shown in Figure 8.14. There were a number of sophisticated and proficient eTSPCK episodes generated in the lessons that did not necessarily speak directly to the test-items. This could be used as an indicator that the PPSTs were not teaching for the test but general to the two intended concepts in Chemical Equilibrium, namely, ***(i) the conditions necessary for Chemical Equilibrium*** and ***(ii) the factors affecting the state of Chemical Equilibrium***.

Secondly, the calculated correlation between the PPSTs' eTSPCK episodes and the learners' achievement revealed an insignificant negative correlation between all the PPSTs' eTSPCK episodes and their respective learner performances in the pre-test. This finding was necessary as it confirmed that the learners had not received any teaching of the concepts on Chemical Equilibrium by the PPSTs' before the pre-test. This understanding, therefore, enabled the study to establish a link between the PPSTs' teaching and learner post-test performances. A significant and positive moderate to high correlation between the PPSTs' eTSPCK episodes and learner performances was established in the post-test, as shown in the summary in Figure 8.15.

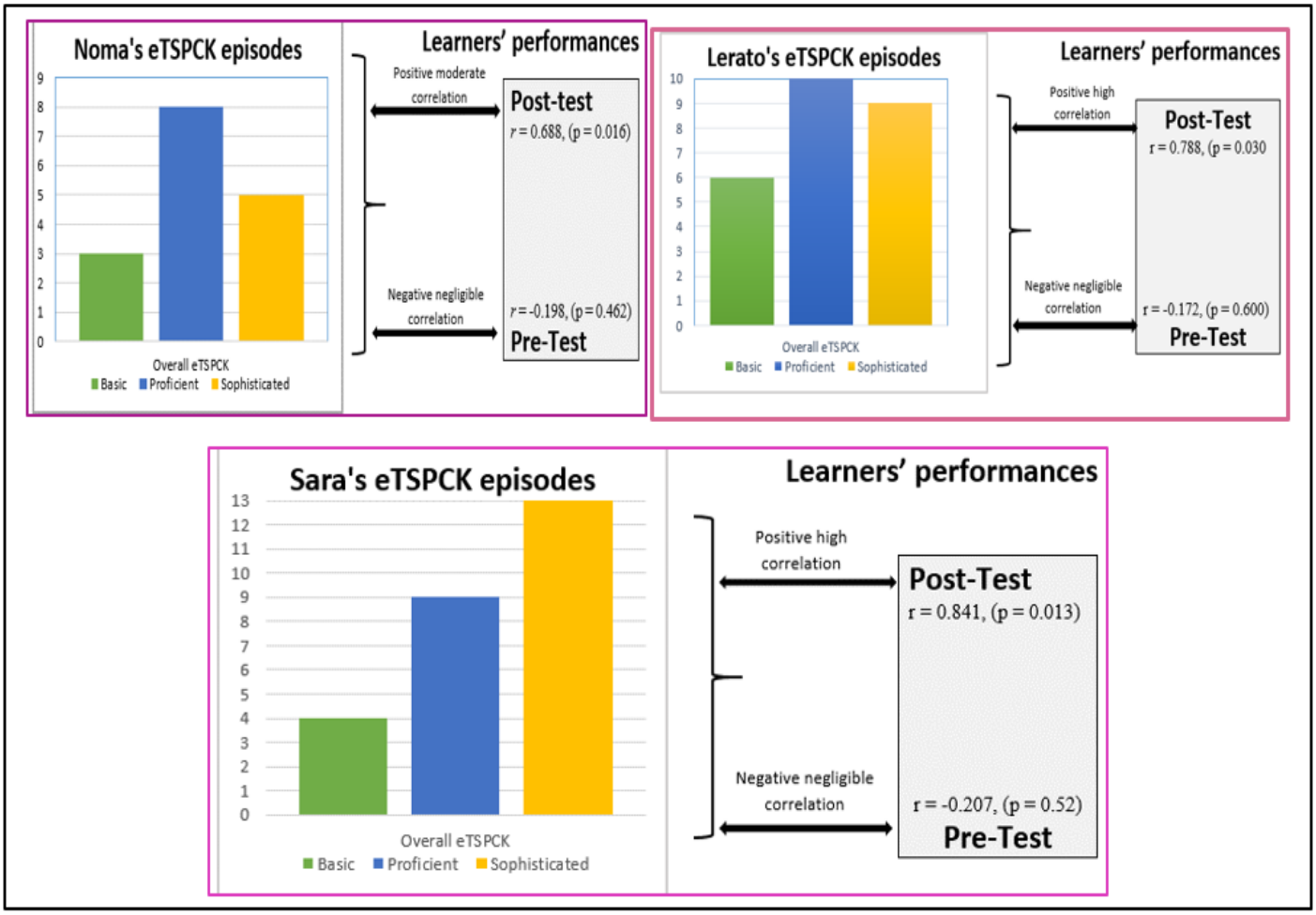


Figure 8. 15: Summative correlation analysis per each PPST

The Pearson correlation coefficients show that r = -0.30 at alpha values, much higher than a significant level of 0.05, were calculated between each of the PPSTs eTSPCK episode Rasch measures and their corresponding learner performances in the pre-test. The negative signage indicated an existence of an inverse relationship between the PPSTs' eTSPCK and learner performances in the pre-test. The coefficient values suggested an insignificant and negative negligible correlation between the PPSTs' TSPCK and learner pre-test performance. However, the Pearson correlation coefficients between r = 0.688 and r = 8.41 at alpha values much lower than the significance level of 0.05 were calculated in the post-test. The coefficient values suggested an existence of a significant moderate to high correlations between the PPSTs' eTSPCK and learner performances in the post-test.

Thirdly, largely sophisticated eTSPCK episodes were found to link evidently to the learners' improved responses in the post-achievement test. This finding is highlighted in Figure 8.15 above and summarized in Figure 8.16 below.

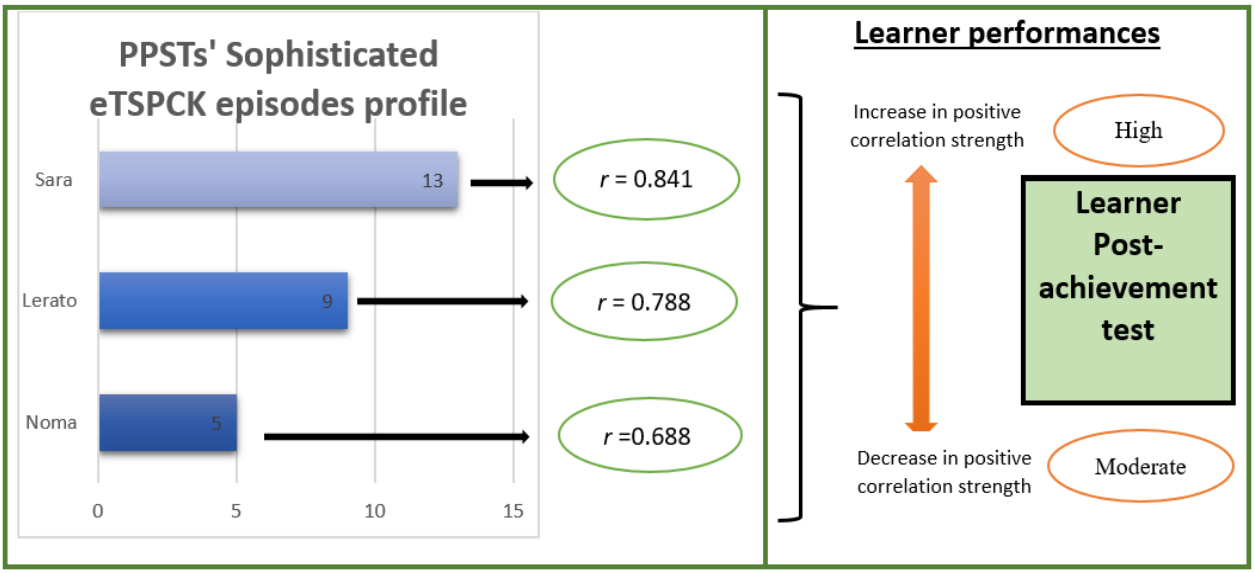


Figure 8. 16: A summary of the relationship between the PPSTs' sophisticated TSPCK and learner performances

The findings in Figure 8.16 revealed presence of a strong correlation between the highest quantity of sophisticated eTSPCK episodes and learner post-test performances in the post-test. For example, a significant moderate positive correlation was established for Noma who had the lowest number of sophisticated eTSPCK episodes (5 episodes) but Sara who had the highest number of eTSPCK episodes (13 episodes) had the highest positive correlation of all the PPSTs.

Lastly, learner views pointed to specific teacher tasks as having visibly assisted their learning. These are: (i) the use of diagrams and graphs, (ii) examples that relate to the learners' everyday encounters, (iii) explicit emphasis when explaining concepts and (iv)projecting the slides that clearly explained the concepts. The first two tasks were common learner views across the three PPSTs' cases. The use of graphs and diagrams implied that the PPSTs viewed/considered an aspect of Representations (R) as important when explaining the concepts. Similarly, the PPSTs' use of examples that are relatable to the learners is an indication of the value of Learner Prior Knowledge (LPK). However, the third task which is specific to emphasizing the important concepts explicitly was specific to Noma, whilst the fourth task was presented by Sara's learners. The last two tasks demonstrate the PPSTs' consideration of an aspect of Curricular Saliency (CS) in their teachings.

This specific TSPCK component speaks to the aspect of what is core and peripheral to the content being taught, hence it points the learners to what they need to understand about the topic. It can then be concluded that three TSPCK components (LPK, R and CS) were considered by the learners as important in enhancing conceptualization. The next chapter is a discussion and recommendation chapter. The Chapter provides a summary of all the findings discussed from the previous chapters.

CHAPTER 9

DISCUSSION AND IMPLICATIONS

This chapter provides a reflective summary of what the study is about, drawing from the discussions in the previous chapters. The findings are discussed in relation to the research questions. The chapter begins with an introduction relating to the theoretical framework that guided this study. Following this is the establishment of the credible baseline of this study which precedes the reflections on empirical findings and discussions corresponding to the research questions. Based on the empirical findings, the implications for PPSTs development within the context of South Africa are drawn. The chapter concludes with the recommendations and suggestions for future research.

9.0. Introduction

The interest of this study was on the development of the teacher professional knowledge of pre-service teachers (PCK), following the PGCE qualification track, referred to briefly as PPSTs. Shulman refers to PCK as uniquely the province of teachers that separates a science teacher from a science specialist (Shulman, 1986). Grounding this study was the acknowledgement of Shulman's (1987) theoretical PCK framework that effective teaching requires transformation of content knowledge whose value can be measured through its effects on learner achievement (Rollnick & Mavhunga, 2015). The study further acknowledges the topic specificity of Pedagogical Content Knowledge (TSPCK).

TSPCK has been defined as the knowledge used to transform content knowledge of a specific topic (Mavhunga, 2016). As it was alluded to in Chapter 2, the construct is defined through the use of five content-knowledge components that distinguishes it from other grain sizes of PCK: Curriculum saliency, learner prior knowledge including misconceptions, what is difficult to understand and teach, the use of representations and analogies and conceptual teaching strategies. The topic specific nature of PCK has been recognized in the Refined Consensus Model of PCK-RCM model (Carlson *et al.*, 2019). The PCK-RCM Model categorized PCK into three grain sizes which are discipline-specific, topic-specific and context-specific PCK, all visible in different realms (Carlson *et al.,* 2019). The first realm, known as collective PCK (cPCK), refers to the PCK knowledge shared by the community. They are acquired through formal courses such as the initial teacher development programmes, where published knowledge is discussed. The second realm is

personal PCK (pPCK). This refers to an individual teacher's own PCK which is visible from the teacher's planning to teach, as planned PCK (plPCK), and during classroom enactment as enacted PCK (ePCK). Both plPCK and ePCK are the teachers' personal PCK (pPCK). In this study, cTSPCK refers to the TSPCK knowledge taught in the formal course, the intervention of this study, plTSPCK as the TSPCK manifesting in the PPSTs' planning to teach and eTSPCK for the TSPCK observed in the classroom enactment. This study desirably explored the development of PPSTs from their acquisition of TSPCK in Chemical Equilibrium, tracking their TSPCK through the cTSPCK-plTSPCK-eTSPCK continuum and their ultimate effect on learner outcomes, as defined in the PCK-RCM model. The significance of exploring TSPCK this way, lies in the fact that very few studies have explored the entire continuum in a single study, particularly with PPSTs whose exposure to PCK and other pedagogies is limited to a single year as opposed to the 4-year period common to traditional pre-service teachers. Thus, this study, reports comprehensively on the PPSTs' multiple dimensions of TSPCK captured as they move from the one PCK realm into another and the ultimate impact of their eTSPCK on learner outcomes. The exploration had to begin on a credible baseline reflecting the PPSTs' TSPCK at the beginning of the study in order to interpret the ensuing shifts of interest with both reliability and validity.

9.1. Establishing a credible baseline of the study: plTSPCK acquired from a cTSPCK based intervention

Establishing a credible baseline is an important foundational step when shifts and growth patterns of participants are explored, as in this study. In this study, the credibility of the baseline was built accumulatively through the employment of a validated intervention through the validated tools used to capture and measure the quality of TSPCK and the actual shift in patterns determined as the findings from the intervention. The development of PPSTs' TSPCK happened through a signature intervention (Mavhunga & Rollnick, 2017) whose content structure has been used widely to improve the quality of TSPCK in various science topics. Examples of empirical studies that have employed the same intervention structure include the development of TSPCK in electrochemistry with in-service teachers (Rollnick & Mavhunga, 2014), in particulate nature of matter with novice uncertified teachers (Pitjeng-Mosabala & Rollnick, 2018), in electric circuits by Mavhunga et al. (2016) with physics pre-service teachers, and recently in Organic Chemistry (Akinyemi, 2020) with chemistry pre-service teachers. These, as well as the present, studies used

signature TSPCK tools, sharing a common item structure, unit of analysis based on the extent of component interaction, but differ in the content of the topic. In each of these cases, the intervention led to an improvement in the quality of the participants' TSPCK. Similar to the previous studies, the same intervention procedures were replicated with a cohort of PGCE physical science PSTs (PPSTs) on a topic of Chemical Equilibrium to confirm the development of their personal TSPCK at a planned level (plTSPCK). Fundamental to the intervention discussions was for the PPSTs to develop generic competence to use the TSPCK framework to transform content knowledge of any given topic into a teachable form. Mavhunga (2016) referred to this as pedagogical transformation competence (PTC). Accordingly, when any topic is reasoned through and transformed using the five content-specific components, a PCK is developed, which is specific to that topic (TSPCK). Mavhunga (2016) then described pedagogical transformation competence as the skill and knowledge to interactively use the TSPCK components to transform content knowledge of any given topic, thereby self-developing TSPCK.

The results of the intervention in this study (Chapter 5) based on the shifts between the pre- and post-TSPCK tools revealed an increase in the PPSTs quality of TSPCK at a planned level (plTSPCK). The quality of the PPSTs' plTSPCK demonstrated a shift of two quality categories, improving from a low category (limited TSPCK) to a higher category (developing TSPCK). The improvement in the quality of PPSTs' plTSPCK was collaborated by the findings from the shifts observed between the pre- and post-CoRes. The post-CoRes showed quality in the depth of explanations that are more comprehensible, and which revealed an improved quality of plTSPCK on the topic of intervention. This shows the strength of the finding as it is triangulated from two different major data sources to validate the outcome. This is the first finding in this study, and it is important as it is for a specifically unique group of participants (PPSTs) who had a limited exposure to pedagogy teaching including TSPCK. It is then comforting that the approach of the intervention that is used with the traditional PSTs who are likely to have additional exposure at different levels of their 4-year study period generated the same improvement for this unique group. Secondly, this finding most importantly validates the baseline from which all shifts can be interpreted as trustworthy and credible findings.

Whilst the repeated finding confirms the trustworthiness of the intervention, it also adds to the support for the call for nationalizing the implementation of the TSPCK construct in preparation of

science teacher education training (Mavhunga & Rollnick, 2017; Akinyemi, 2020), and a possible response to the core practice movement (McDonald *et al.*, 2013) that called all disciplines to forward what is regarded as core competences in their respective fields. Section 9.2 discusses the study's key contributions to new knowledge.

9.2. Contributions to New Knowledge

Emerging from this study are four key findings that contribute to new knowledge and expand our understanding of PCK as the teacher knowledge for teaching science. The first contribution is with regard to the development of PPSTs' TSPCK observed in planning and its translation for use in classroom enactment in similar patterns as that reported widely with traditional pre-service teachers. This finding is important in understanding PGCE as a route to fast-track the production of qualified science teachers, particularly for the developing countries, such as South Africa, burdened with poor learner performance in science. The thought of PPSTs who could deliver sound science lessons on arrival in schools is attractive. The second important new contribution is with regard to the established, conclusive and significant correlation between eTSPCK and learner outcomes. There have been contradicting studies casting doubt about the direct correlation of teachers' PCK to learner outcomes in the literature. The third finding is with regard to the new PCK-RCM model that presents the teachers' PCK development trajectory as the cTSPCK-plTSPCK-eTSPCK continuum and the ultimate link to learner outcomes. The continuum is one of the important features of the newly produced PCK-RCM model which was, however, conceived systematically from theoretical rather than empirical arguments. The fourth and last finding is with regard to what the learners perceived as important qualities that reflected the TSPCK of the PPSTs. The finding is important in explaining which elements of the PPSTs' teaching might have amplified, or filtered learners' understanding of the concepts of Chemical Equilibrium and thus need emphasis on the intervention. The findings in this study add to the literature the much-needed empirical evidence that validates the conceptually conceived cTSPCK-plTSPCK-eTSPCK development continuum in the PCK-RCM model. The discussion below unpacks each of these findings.

9.2.1. The development of PPSTs' plTSPCK and eTSPCK

The complex and tacit nature of PCK, requires that it be explained by looking at not only what a teacher knows about teaching a topic usually observed in their planning for teaching, but also their classroom enactment (Aydeniz & Kirbulut, 2014). The examination of PCK across the two realms provides richer insights into understanding the PCK development and subsequently its manifestation in the actual classroom teaching. This section provides insights into the relationship between the PPSTs' plTSPCK and eTSPCK by investigating the development of their PCK in Chemical Equilibrium, from an intervention and its demonstration in both the PCK realms. The gist of the discussions in the intervention was on the interactive use of individual TSPCK components when explaining the concepts of Chemical Equilibrium, to produce a more comprehensible content. The findings revealed congruence between the PPSTs TSPCK in planning and actual classroom contexts. Recalled from Chapter 5, the analysis revealed an improvement in the quality of the PPSTs' plTSPCK which shifted from a limited category to a developing category of TSPCK in the pre- and post-TSPCK test, respectively. Their post-TSPCK test responses portrayed the PPSTs' ability to interactively use multiple TSPCK components in their explanations. This was the main signature driving the intervention discussions. Similarly, the analysis in Chapter 6, which focused on a subset of 3 PPSTs' eTSPCK from their actual classroom teachings, revealed that their lessons were dominated by proficient (28) TSPCK episodes followed by sophisticated (25) and basic (14) TSPCK episodes. The emergence of developing and proficient TSPCK episodes in the quality of the PPSTs' plTSPCK when planning to teach and in the actual classroom enactment (eTSPCK) signified by an interactive use of three components, indicates a similarity in the PPSTs' personal TSPCK seen in planning (plTSPCK) and in classroom teaching (eTSPCK) of Chemical Equilibrium.

For a closer look into the relationship and links between the PPSTs' TSPCK across planning (plTSPCK) and classroom enactment (eTSPCK), Sara's typical case is discussed further.

Sara's personal TSPCK in planning (plTSPCK) and enactment (eTSPCK)

A planned TSPCK (plTSPCK): The PPSTs' plTSPCK was explicitly discussed in Chapter 5 using data collected through pre-and post-TSPCK test tools and the post-CoRe, including the intervention discussions and presentations by the PPSTs. This enabled the study to track a

progressive development of the PPSTs plTSPCK as it was developing, until the end of the intervention. One example extracted from the TSPCK-tool as analyzed in Chapter 5 is that of item 1 in the TSPCK tool. The item was based on a doubt projected by a learner (considered to result in a misconception) about the reactions at Chemical Equilibrium as the learner asked whether *"both the forward and the backward reaction actually take place if a closed system is at equilibrium?"* The question required the PPSTs to choose the best response which they considered appropriate to address and clear the learner doubt from a given list of responses. The question further requested that they expand on their choice of response (see Chapter 5; section 5.1.2a). As explicitly discussed in Chapters 3 and 5, the TSPCK tool questions are structured using the five TSPCK components to capture the teachers' knowledge and understanding of the TSPCK construct. Accordingly, item 1 which was based on a learner doubt examined the ability of the PPSTs to identify a learner misconception and provide an explanation that rectifies that misconception. Figure 5.14 in Chapter 5 portrays the pre- and post-TSPCK test responses by Sara for item 1. In her pre-TSPCK test, Sara's response was categorized at a Limited level. As Sara attempted to address this misconception, she indicated that when a reaction has reached a Chemical Equilibrium state, both forward and reverse reactions are happening at the same rate (WD). Expanding to this, Sara's explanation displayed her own misconception, as she indicated that the "amount" of products and reactants are equal at equilibrium. The post-TSPCK response which was scored at a Developing level showed an improved understanding as the explanation displayed a greater ability to deal with a learner misconception and move a learner towards the correct knowledge of concepts. Sara began her response by showing that the two reactions are happening simultaneously and the rates for the forward and reverse reactions are equal at Chemical Equilibrium. An aspect of curricular saliency (CS) surfaced when Sara indicated that those are the characteristics of chemical Equilibrium (see Chapter 5; Figure 5.14). She explained this further by showing that at Chemical Equilibrium, the concentrations of reactants and products at Equilibrium must not necessarily be equal but should remain constant. The response shows that Sara was mindful of one of the common learner misconceptions with regard to concentrations of reactants and products at Chemical Equilibrium, with the learners believing that concentrations are equal (LPK). To emphasize this further, Sara ended her explanation by suggesting that *"…the graphs of concentration vs. time and rate vs. time help the teacher to explain the difference between equal rate and constant concentrations"* which shows her understanding of the concept of

representations (R) and the improvement of her own conceptual understanding, as discussed in the intervention (see Chapter 4; section 4.3.5). The post-TSPCK responses by Sara resulted in an interactive use of three TSPCK components **CS/LPK/R** improving from a one TSPCK component explanation in the pre-TSPCK test. Sara's competence displayed in her interactive use of multiple components in an explanation seems to reflect back to the focus of the intervention, growing her personal TSPCK in a context of planning to teach (plTSPCK) and thus enabled her to provide teacher explanations with more depth. Furthermore, a certain portion of this development can be ascribed to improvement in content knowledge (Davidowitz & Potgiter, 2016).

Enacted TSPCK (eTSPCK): One of the Big Ideas of Chemical Equilibrium that the PPSTs had to teach in their lessons was "conditions necessary for Chemical Equilibrium". One aspect related to this Big Idea concept has to do with reversible reactions. As discussed in Chapter 4, amongst the learners' common misconceptions around the topic of Chemical Equilibrium is that "there is no reaction at Chemical Equilibrium". During a tutorial presentation which resulted in the intervention, Sara showed the importance of emphasizing the concept of reversibility, including its simultaneous and continuous nature, to address the same misconception. She related this misconception to the inability of the learners to visually see the particles' rearrangements in chemical reactions that happen at a macroscopic level in the laboratory. The same misconception was envisaged by Sara in her post-CoRe and lesson planning and associated with the microscopic nature of chemical reactions done in the laboratory. Sara suggested the use of representations such as a scenario of water changing phase coupled with its microscopic and symbolic chemical equations to address this and improve conceptual understanding. The lesson plan presented a single sophisticated TSPCK episode for the teaching of a concept of reversibility (CS/R/LPK-WD). In her actual teaching of reversibility of chemical reactions (see Chapter 6; Table 6.7, TSPCK episode 3), Sara began this segment by explaining that Chemical Equilibrium can only be achieved for reversible reactions. This teaching episode came after an episode that reviewed the irreversible reactions which she argued would help the learners to differentiate between reactions that go to completion versus reversible reactions that do not go to completion. The aspect of reversibility is an important condition for Chemical Equilibrium. It shows that Sara understood the aspect of curricular saliency (CS). Using a question-and-answer method to probe on the learners' knowledge of the concept of reversibility, Sara explained this further using a symbolic chemical reaction on the formation of Ammonia gas through the Haber process. The question-and-answer strategy

brought about an aspect of LPK, whilst reference to the Haber process reaction brought through a symbolic representation (R). She further added that in this reaction, a reverse reaction that involves ammonia gas breaking into its original reactants (H_2 and N_2) begins before the completion of the forward reaction ($N_2 + H_2 \leftrightarrow NH_3$), thus emphasizing that this is a continuous reaction that does not go to completion. Two components of TSPCK: WD and LPK in the form of misconception came to play in this explanation. Sara's emphasis that reversible reactions do not go to completion indicates that she was mindful of the common learner misconception that "*there is no reaction happening at equilibrium*". The explanations given by Sara were similar to the discussions held in the intervention on the concept of reversibility and the dynamic nature of chemical equilibrium, also observed in her tutorial presentation response and the post-TSPCK response. Her teaching of this concept resulted in a sophisticated TSPCK episode **(CS/LPK/R/LPK/WD),** displaying an interactive use of four different TSPCK components, with an LPK component repeating. The integration of multiple TSPCK components in an explanation seems to reflect back to the focus of discussions of the intervention on the importance of an interactive use of TSPCK components when transforming the content knowledge of a topic of Chemical Equilibrium to produce a more comprehensible format. This competence was also displayed when analyzing Sara's plTSPCK, as demonstrated above where the response displayed an interactive use of three TSPCK components, categorizing the episode at a developing level. Multiple other episodes (of different TSPCK category levels) following this emerged. They put more emphasis on the simultaneous nature of reversible reactions, using different representations such as "water changing phase" and graphs. This resonates with the findings by Mavhunga and van der Merwe (2020) that a single TSPCK episode identified from a lesson plan re-surfaced in clusters of episodes in the classroom lessons. This assisted with removing the common learner misconception referred to above, that there is no reaction at Chemical Equilibrium and that the forward reaction has to go to completion before a reverse reaction starts. Furthermore, episode 17 (see Chapter 6, Table 6.7) reveals the learners' response on the dynamic equilibrium. The correct response that the learners gave showed that they understood the explanations that Sara gave regarding the simultaneous and continuous nature of reactions at equilibrium. These findings revealed a similarity in the pedagogical transformation competence (PTC) seen in the high quality of TSPCK demonstrated across planning (plTSPCK) and enactment (eTSPCK) on a topic of Chemical Equilibrium.

The paragraphs above empirically demonstrated how the planned TSPCK translated into enactment in the topic of Chemical Equilibrium and revealed the similarities between the two realms of PCK. This finding expands on the existing understanding, in the literature, on the importance of interactions among TSPCK components which is crucial to the quality and development of PCK in a given topic, as opposed to the knowledge of individual components (Nilsson & Karlsson, 2019; Park & Chen, 2012). The understanding of the link between the PPSTs' plTSPCK and eTSPCK across the two PCK realms is new knowledge that has not been examined in the PCK literature. This finding provides an understanding of how the TSPCK construct can be used in initial teacher training of PGCE pre-service teachers to develop sound personal TSPCK. The thought of using the same signature intervention in the PGCE programmes to develop PPSTs' whose delivery of the lessons is sound and understood by the learners on arrival in schools is an exciting finding extending our understanding of making most in the PGCE as a route to fast-track the production of qualified science teachers, particularly for developing countries such as South Africa which are burdened with poor learner performance in science.

9.2.2. The correlation between PPSTs eTSPCK and learner outcomes

One of the study's major aims was to trace the development of the PPSTs' acquired TSPCK through planning to teach (plTSPCK), its manifestation into classroom enactment (eTSPCK) and the ultimate link to learner performance in Chemical Equilibrium. The teacher TSPCK-learner outcomes relationship was explored by calculating correlation. Chapter 7 of this study analyzed the learner conceptual performance on Chemical Equilibrium concepts captured through their pre- and post-learner's achievement tests. The analysis revealed a significant improvement in learner conceptual performance as a direct impact of the PPSTs teachings. Chapter 8 analyzed the correlation between the PPSTs eTSPCK and learner outcomes, and a positive significant correlation was established to exist between the PPSTs' eTSPCK and learner performance in the post-achievement test. In this section I discuss the established correlation between the PPSTs' eTSPCK and learner performances as reported in Chapter 8. The chapter begins by reflecting back on the learner performances reported in Chapter 7.

Reflecting on learner achievement

Two learner-achievement tests were administered to 3 different groups of learners from the 3 PPSTs classes, as observed in Chapter 7. Pre-learner achievement tests were administered before any teaching by the PPSTs and the post-achievement tests followed immediately after the teaching by the PPSTs. An analysis of these tests involved: (i) the marking of the tests, using a memorandum of correct answers, and an interpretation of the raw scores to establish the development/gain in the learners' scores (see Chapter 7, Table 7.4) and (ii) the raw scores turned into Rasch measures, using the Winstep Rasch Analysis model to assist in measuring the significance of the learner performance knowledge gain (see Chapter 7, Table 7.5). All the learners from the 3 PPSTs classes registered a significant improvement from the lower test scores in the pre-tests to the higher scores in the post-tests. Their overall raw test score performance, across all three PPSTs improved from an average performance of 33.3% in the pre-test to an overall average of 75% in the post-achievement test, thus indicating a knowledge gain of 41.7%. The results pointed to a significant improvement in the learner outcomes for the topic of Chemical Equilibrium following the teaching by each of the PPSTs. When the data were converted to Rasch analysis, similarly, the overall Rasch person measures for all the PPSTs' learners improved following the teaching by the PPSTs. For example, Noma's learners had an average Rasch person measure of -1.58 which increased to 2.97 logits following Noma's teaching. Lerato's learners saw an average pre-test Rasch person measure of -1.08 and a post-test Rasch person measure of 2.54. Accordingly, the Rasch person measures of Sara's learners improved from -0.29 to 4.41 logits in the pre- and post-tests, respectively. Across the 3 PPSTs' lessons, the learners experienced overall Rasch person measures of 4.55, 3.62 and 4.73 logits as the knowledge gains for Noma, Lerato and Sara, respectively. An improvement in the Rasch person measures is proof that learning had occurred hence the learners gained knowledge of concepts related to Chemical Equilibrium after being taught by the PPSTs. Although this study was focused on the PGCE cohort of physical science PSTs, a group that was exposed to a TSPCK construct for a short period of time in their 1-year programme, it is highly encouraging that the change in their learners' conceptual performances was found to be significant following their teaching. The findings are significant in the context of breaking the back of poor learner performance in South Africa by delivering, expeditiously, teachers who have such influence through the PGCE track. The findings portrayed herein are similar to those by Akinyemi (2020) whose focus was on the fourth year B Ed PSTs' TSPCK-learner outcomes link on a topic of

Organic Chemistry. Similarly, Akinyemi's findings revealed a high significant improvement in each of the PSTs' learner performances on the topic of Organic Chemistry (Akinyemi, 2020).The findings in this study were also consistent with those revealed in the previous studies(such as Sadler *et al.*, 2013) which investigated the influence of physical science teachers' knowledge on student learning and Keller et al. (2017) who examined the impact of physics teachers' PCK and motivation on the learners' interest and achievement.

Reflection on the methodology for analysis of correlation between the PPSTs' eTSPCK and learner performances

The correlation between the PPSTs' eTSPCK against learner performance on a topic of Chemical Equilibrium was exhaustively analyzed and reported in Chapter 8. Although the study tracked and reported on the different realms of TSPCK by explaining the cTSPCK-plTSPCK-eTSPCK trajectory, the PPSTs' TSPCK which was selected for exploration to have a direct link to learner performances is the one revealed in the actual classroom teaching (eTSPCK). It is the closest form of PPSTs' TSPCK that the learners were exposed to. Many factors have been found to have an effect on learner performance in the classroom, thus reducing its direct linkage to the PPSTs TSPCK. These factors include teacher content knowledge, pedagogical knowledge, student and teacher beliefs etc. (Gess-Newsome, 2015). The study therefore acknowledges this complexity of teaching and learning, hence precautions were taken during the analysis to interpret the TSPCK-learner outcome relationship, as exactly reflecting the relationship rather than causality.

In order to be able to analyze the data for correlation between the two variables (PPSTs' eTSPCK versus learner performances), the study first analyzed the data for the PPSTs' eTSPCK (see Chapter 6) by purposefully identifying the teaching segments that were strictly TSPCK episodes. It was then important that those lessons display the evidence of TSPCK episodes referred throughout the study as the moments in teaching that revealed an interaction between two or more TSPCK components in an explanation of the concepts. This analysis was done separately from other factors that might have impacted on the classroom enactment as a precautionary measure to sift and reduce the impact of other possible factors. Furthermore, while the PPSTs were aware of the learner-achievement tests, the details of the content of the tests were concealed and not known to any of them. In order that the PPSTs would not teach the test but rather provide a high-quality instruction that efficiently contributed to the learners' understanding of the Big Ideas of the topic

(Chemical Equilibrium) they were required to teach the ***conditions for Chemical Equilibrium*** and ***the factors that affect chemical reactions at a state of Chemical Equilibrium***. On analyzing the data for the correlation (as presented in Chapter 8), the first step was to ensure that only the test items that were covered by the PPSTs in their teaching were included in the analysis. Fortunately, all the test-items were covered in each of the PPSTs' teaching. This refinement of data was done to ensure the credibility of the correlation analysis and thus to ensure that TSPCK could be examined independently as one factor that could be used to improve the learner performance. Having sifted out the effect of TSPCK and other factors that may have impacted on the classroom enactment, the correlation analysis followed between the PPSTs eTSPCK episodes and learner performances. The analysis focused on the overall TSPCK episodes against the learners' pre-and post-achievement test performances, respectively. The overall TSPCK episodes were found to have clusters of TSPCK episodes of different categories that all worked together to enhance learner understanding of concepts. This observation was made during the data analysis, in preparation for the calculation of the correlation to determine the TSPCK-learner outcome link. It was through this in-depth qualitative process that an observation was made revealing that a single test-item was linked to multiple TSPCK episodes, identified as episode clusters and all working together to explain and strengthen the learners' understanding of a concept (Akinyemi, 2020; Mavhunga & van der Merwe, 2020). Using the PPSTs' overall TSPCK episodes emerging from their teaching was therefore a way of acknowledging all the efforts that they put in ensuring that the learners understood the concepts. A statistical correlation process then followed to establish the relationship between the Rasch measures of the PPSTs' eTSPCK episodes and learner performance. Moreover, the calculation of correlation required that the data be paired. Therefore, in cases of unpaired observations, a strategic random sampling is advised to satisfy the principle of pairing of variables for correlation analysis (Lorenz *et al.,* 2018). For this reason, the study employed random sampling of the two variables (TSPCK episodes versus learner performances) through the multiple permutations of the pairing of data sets. For each PPST, three batches of paired data sets were done for the analysis of the correlation between the PPSTs' eTSPCK episodes and learner performance. The 3 batches were considered in this study as fitting and assisting with accuracy of the results to measure the overall relationship between the two variables. As a way to minimize bias, each batch selected for further correlation analysis had to consist of data that was not included in the random selection of data for the previous batches (Lorenz *et al.,* 2018). For reliability and credibility of

the findings, three independent raters who are also TSPCK researchers assisted with the entire correlation analysis. They also assisted with the identification of TSPCK episodes from the PPSTs' teaching, identifying TSPCK episodes that matched directly to individual test items in the learner achievement tests, including a process of strategic random sampling of TSPCK episodes and the learners' conceptual performance. All these processes were repeated until the consensus could be reached between all the raters and myself, thus ensuring the credibility of the findings.

Reflecting on the correlation results; the PPSTs' eTSPCK against learner performance

One major finding of the study was revealed in the analysis of the correlation between the PPSTs overall eTSPCK episodes versus learner performances (Figure 8.1). First, the analysis between each of the PPSTs' overall TSPCK versus learner performances in the pre-test revealed the correlation coefficients of $r = -0.198$ ($p = 0.483$), $r = -0.172$ ($p = 0.600$) and $r = -0.207$ ($p = 0.52$) for Noma, Lerato and Sara, respectively. The correlation coefficients across the 3 PPSTs' cases show an insignificant correlation due to the alpha values that are higher than the significant level, $\alpha = 0.05$. The findings revealed the presence of a statistically insignificant and negative negligible correlation between the PPSTs' overall TSPCK episodes and the learners' performances before the teaching by the PPSTs. The negligible correlation was not a surprise as the learners had not received any teaching of the concepts on Chemical Equilibrium by the PPSTs' before. These patterns are similar to those in other studies that have employed correlations (Sadler *et al.,* 2013; Fortsch *et al.,* 2016; Akinyemi, 2020). Contrary to this, the correlation coefficients for the analysis of the PPSTs overall eTSPCK episode and learner performances in the post-test; $r = 0.688$ ($p = 0.016$), $r = 0.788$ ($p = 0.030$) and $r = 0.841$ ($p = 0.013$) at the alpha values much lower than the significant level, $\alpha = 0.05$ were revealed for Noma, Lerato and Sara, respectively. A significant positive correlation is revealed to exist between the PPSTs' overall eTSPCK and learner performance, following the PPSTs' teaching. The findings indicate the presence of a relationship between the PPSTs' eTSPCK episodes and the learner performance observed after the teaching by the PPSTs (see Chapter 8, Figure 8.1).

Furthermore, the analysis revealed the existence of a positive correlation between the PPSTs' sophisticated TSPCK episodes and the learners' high post-test item performances in Chemical Equilibrium. A positive correlation refers to a linear and direct relationship between two variables being investigated, whereby as the value of one variable increases, so does the value of another

variable (Schober *et al.*, 2018). In this study, this implies a direct association between high quality explanations given by the PPSTs to the high learner performance and understanding of concepts. This finding provides an understanding of how the TSPCK construct can be used in the training of PGCE pre-service teachers to develop a sound personal TSPCK that results in effective teaching which, in turn, enhance learning. This finding provides evidence of the potential in the use of the TSPCK construct to fast-track the development of high-quality teachers using a time-constrained 1-year PGCE programme. While multiple studies have discussed the link between teachers' PCK and learner outcomes (Alonzo *et al*., 2012; Förtsch *et al*., 2016; Keller *et al*., 2017), there is limited literature on the studies that investigated the cPCK-plPCK-ePCK continuum link to the learner outcomes (Akinyemi, 2020). This study therefore contributes to these findings from the PGCE pre-service teacher perspective

For example, in the case of Sara whose lesson consisted of the highest number of sophisticated TSPCK episodes compared to the proficient and basic episodes, there existed the highest positive significant correlation between the eTSPCK episodes and the learner post-test performance. The correlation was moderate in the case of Noma, whose lesson consisted of the highest number of proficient TSPCK episodes. The observed difference in the correlation coefficients was brought about by the quantity of the sophisticated TSPCK episodes per PPST's teaching compared to other categories of TSPCK (proficient and basic levels). A sophisticated TSPCK episode resembles the highest category of TSPCK, indicating the PPST's most developed level and ability to transform content knowledge into a teachable form. The demonstrated high and moderate correlations suggest that the correlation gradient is in cognizance with the different qualities of TSPCK episodes. This coincides with what Miheso (2018) has shown that the combination of a high number of proficient and sophisticated TSPCK episodes in one's teaching designates a more developed TSPCK. Similarly, a low developed TSPCK is argued for a combination of a high quantity of basic and proficient TSPCK episodes. This finding therefore suggests a relationship between a more-developed TSPCK and the learners' high post-test performance. The direct association between the PGCE pre-service teachers' overall TSPCK episodes and the learners' post-test performance contributes to the reliability of the correlation analysis, thus suggesting that TSPCK can be considered as a factor when examining learner performance.

The established positive correlation between all the 3 PPSTs' TSPCK episodes and learner post-test performance is consistent with the results from the previous studies that reported a positive correlation between teachers' general PCK and learner performance (Fortsch *et al.,* 2016; Sadler *et al.,* 2013; Mansor *et al.,* 2010) and more precisely, a study by Akinyemi (2020) whose findings revealed a high positive correlation between the PSTs' eTSPCK and learner performances. This confirms the reliability of the methodology followed for the correlation analysis which was first used by Akinyemi (2020) and which also points out to the use of teachers' TSPCK to investigate learner performance. Several studies have however found no correlation between the observed teachers' broad PCK and learner achievement (Liepertz & Borowski, 2019; Gess-Newsome *et al*., 2019). This finding contradicted the study by Gess-Newsome et al. (2019) which revealed a strong positive association between the learners' learning and teachers' perceptions about the changes in their teaching practice. Similarly, while Liepertz and Borowski (2019) had assumed that teachers who have higher professional knowledge can provide a worthwhile learning environment which initiates the learners' understanding, the analysis of their data revealed a negative correlation between the observed teachers' PCK and learner achievement. These inconsistencies in the findings have resulted in mixed signals to the PCK community, which left the issue unresolved. The contradictions, in my view, may be assigned to the difference in the methodologies used and the conceptualizations of PCK. For example, the two studies by Liepertz and Borowski (2019) and Gess-Newsome et al. (2019) used the discipline specific grain size of conceptualization while focusing on specific topics.

For science education, understanding the relationship between the teachers' PCK and learner outcomes with certainty is the missing piece in fully describing the integral output of the PCK theoretical construct on learning science. The ultimate proof would be the calculation of a causal effect between the quality of teachers' PCK and learner outcomes. However, such a calculation would first need a convincing proof that there is a relationship between PCK and learner outcomes to start with. Thus, the importance of the positive correlation calculated in the present study contributes towards the pool of studies that are building convincing findings about the relationship. This study contributes from the context of PGCE pre-service teachers.

9.2.3. The cTSPCK-plTSPCK-eTSPCK trajectory link to learner outcomes

With PCK regarded by research as contributing to learner achievement (Kind, 2017; Kind 2018), the discussions above aimed at explaining the empirical demonstration of the cTSPCK-plTSPCK-eTSPCK continuum link to learner outcomes on a topic of Chemical Equilibrium. This also resonates with what most studies have attested to that it is important to establish not only what the teacher knows, but also what they are able to do in the classroom in order to determine the relationship between teacher knowledge, teaching and student learning (Aydeniz & Kirbulut, 2014; Park & Oliver, 2008). Likewise, Adadan and Oner, (2014), have argued on the importance of understanding how teachers' PCK progresses from preparation through actual teaching to ensure for effective learning. Therefore, focusing on what the PSTs know in teacher education programmes including what they eventually do in the classroom can be used to ensure proficiency of their development (Ball & Forzani, 2009; Mathewson & Reid, 2017).

While a few empirical studies to date have assessed the relationship between science teacher knowledge (PCK) and learner outcomes (Akinyemi, 2020), this study has contributed to similar findings through tracking the PPSTs knowledge for teaching Chemical Equilibrium (plTSPCK), how it translated into actual classroom enactment which revealed their eTSPCK and how this ultimately impacted on learner conceptual performances of Chemical Equilibrium. Acknowledging that PCK and its associate TSPCK is not transferable (Mavhunga, 2016), this study provided the empirical evidence that the competence gained in the context of planning to teach through exposure to cTSPCK to develop plTSPCK is transferable into classroom teaching captured as eTSPCK. While the integration of TSPCK components to explain concepts was at the heart of the intervention discussions, this competence was observed in the PPSTs' planning and teaching, indicating a consistent link across the three realms of TSPCK. This is consistent with the findings in the previous studies (Mavhunga& van der Merwe, 2020; Akinyemi, 2020) who found the planned TSPCK of pre-service teachers to be visible in more complex and clustered manner in actual classroom teaching. However, the finding contradicts the finding by Mazibe et al. (2020) who found that the teachers' reported/planned PCK was not necessarily a reflection of their enacted PCK. The difference between the contradicting studies points to the powerful influence of a PCK-based intervention. This study therefore provided empirical evidence that validates the

conceptually conceived cTSPCK-plTSPCK-eTSPCK continuum link to learner outcomes in the PCK-RCM model.

9.2.4. Reflection on elements that exposed the quality of the PPSTs' TSPCK by the learners

In addition to reporting on the correlation analysis between the PPSTs' TSPCK episodes and learner performance, Chapter 8 also presented on the learners' views about what the PPSTs' did in the classroom that contributed or hindered their understanding of the topic content. Common to all the learners' responses was that the PPSTs used diagrams, provided everyday life examples that they could easily relate to and repeatedly emphasized the important concepts and giving explanations that were accessible to the learners. This indicates the PPSTs' understanding of TSPCK construct which includes aspects of representations (R), learner-prior knowledge (LPK) and aspects of curricular saliency (CS). The learners' views then acted as confirmation to the PPSTs' quality of eTSPCK observed in their interactive use of R, LPK and CS as the components that dominated and shaped their eTSPCK (see Chapter 6). While the use of representations such as diagrams, simulation videos, scenarios etc., has been confirmed to enhance conceptual understanding (Mitchell *et. al.,* 2014), research has also shown that learning becomes more effective when it builds on the existing knowledge (Kurnaz & Sağlam-Arslan, 2011). Carlson and Daehler (2019, p. 88) observe that "Knowledge of students … has a great influence on a teacher's pedagogical reasoning and their cycle of planning, teaching, and reflecting". This correlates with the findings in this study where learner-teacher interactions appeared to result in rich teacher explanations that were more meaningful to the learners with TSPCK component interactions that portrayed high quality TSPCK. It also implies that, while the PPSTs' eTSPCK contributed to the learners' improved performance, the learner engagements also influenced to the observed quality of the PPSTs eTSPCK, which reveals a two-way eTSPCK ↔ learner outcome link. Such moments were observed when the learners asked or responded to the questions by the PPSTs which aimed to establish their prior knowledge. Although the 3 PPSTs' teaching revealed these features in their lessons (especially the questioning and dialogue format), Sara's lesson projected the most learner interactions, with the learner responses demonstrating a deeper understanding of the concepts (see Finding 3 of Chapter 6). The TSPCK episodes triggered by these engagements were classified under two quality categories which are proficient and sophisticated levels. These explanations carried more meaning and were thus well-received by the learners as projected in their responses

which revealed evidence of understanding, both during the lessons and after the PPSTs' teachings in the learner post-achievement tests. This finding supports the understanding that learners are active participants in their own learning (Lee & Branch, 2018), including that teacher-student interactions can contribute to enhancing learner outcomes (Ajjawi & Boud, 2017; Tan *et al*., 2019). While the component of representation (R) was a dominating factor across all those eTSPCK episodes, concepts of LPK and CS were also common across most episodes. The interactive use of the three components of TSPCK (R, LPK and CS) is suggested by the learners as the elements of their PPSTs that contributed to their understanding of the concepts, as presented in the above sections. This observation supports the existing understanding in the literature that the learners' perceptions can be used to get information on the quality of their teachers' PCK (Halim *et al.,* 2013).

Furthermore, in case of Sara whose teaching was dominated by sophisticated TSPCK episodes and whose eTSPCK correlation was highly correlated with post-test learner performance, her learners showed that getting more examples would have improved their understanding further. In the case of Noma, whose lesson consisted of the lowest number of sophisticated TSPCK episodes, with a moderate correlation between her eTSPCK and post-test learner performance, the learners' views called for the use of more examples and video simulations on Chemical Equilibrium. The responses reflecting on the learners' views show that they can tell when explanations given are not strong enough and lack clarity. Hence Noma's learners needed videos to give meaning to the concepts which were apparently not meaningfully explained. This supports the understanding in the literature that the learners' views can also be used to get information on the quality of their teachers' PCK (Halim *et al.,* 2013). Furthermore, the knowledge of learners' perspectives can enable teachers to understand and hence appreciate the instructional processes that influence students' learning, including how to improve their teaching processes (Senocak, 2009; Halim *et al.,* 2013). This is similar to Park and Oliver's (2008) view that science teachers have to get sensitized to the needs of the learners, and this can help them to think of how to improve the quality of their instructions. This understanding may, as a result, contribute to the development of their teachers' PCK (Halim *et al.,* 2013). The understanding of this view can be helpful to the science teacher educators to know which knowledge components to emphasize during the development of the PPSTs' TSPCK. Accordingly, the knowledge of different TSPCK components including the competence to effectively use multiple components to produce meaningful explanations in one's

planning and teaching is essential. It can therefore be concluded that the learners' views reveal the features that reflect the quality of the PPSTs' eTSPCK that resonates with the learners. It further confirms the learners' ability to identify quality in teachers' eTSPCK (Halim *et al.,* 2013).

9.3. Summary of research questions

The main question that this study sought to answer was: How does the competence to pedagogically transform content knowledge of Chemical Equilibrium learned by PGCE PSTs influence their quality of personal TSPCK and its relationship to learner achievement?

First, it was necessary to elaborate on the theoretical framework and the models used to investigate the problem as discussed in Chapter 2. It was equally important to clearly explain the research methodology followed to enable the mixed-method approach to be used for data collection and analysis in Chapter 3. The main research question was re-structured into three sub-questions. All of them aimed at tracking the influence of the learned competence to pedagogically transform content knowledge based on collective TSPCK as seen in planning to teach and classroom enactment related to the learner performance in Chemical Equilibrium. A summary of the findings from this study in relation to the sub-research questions, conclusions and recommendations on these are given below.

Research question 1:

What is the quality of TSPCK displayed by the PGCE pre-service teachers in their planning to teach Chemical Equilibrium, following the explicit discussions of the intervention that aimed at developing their knowledge to teach Chemical Equilibrium?

This research question was intended to establish a credible baseline from which the TSPCK seen in the actual classroom teaching (eTSPCK) and the possible relationship to the learner performances could be based. First, the PPSTs were exposed to explicit discussions of each of the five TSPCK components used in pedagogically transforming content knowledge in Chemical Equilibrium as reported in Chapter 4. The main emphasis of these discussions was the interactive use of these content-specific components when transforming content. As discussed in Chapter 5, the findings revealed an improvement in the quality of the PPSTs' planned TSPCK from a lower category Limited TSPCK level in the pre-TSPCK test, to a higher Developing TSPCK category in the post-TSPCK test. The PPSTs' written responses in the post-TSPCK test and CoRe tool

revealed an improved ability to interactively use multiple TSPCK components in an explanation. This indicated a successful application of competence learned through the intervention categorizing their plTSPCK at a developing level.

The response to this question is:

The intervention improved the quality of the PPSTs' planned TSPCK in Chemical Equilibrium. This was observed in the PPSTs' interactive use of TSPCK components, shifting from an initial category of 'limited TSPCK' by 2 jumps to the category called 'developing level of TSPCK,' following the intervention.

Research question 2: The second research question was:

What is the quality of the PGCE's TSPCK observed in classroom teaching and in what ways is does it reflect the observed TSPCK in planning?

Chapter 6 reported on the findings that revealed the nature and quality of the PPSTs' eTSPCK in the actual classroom teaching of Chemical Equilibrium which were captured through an in-depth qualitative analysis by identifying the TSPCK episodes and then categorized using the eTSPCK rubric.

Firstly, the findings revealed the presence of basic, proficient and sophisticated TSPCK episodes across all the PPSTs' teaching. The emerging episodes from the PPSTs' teaching were largely proficient. This is similar in quality to the 'developing level of TSPCK' that described the PPSTs' TSPCK from planning to teach (plTSPCK). It involves an interactive use of three TSPCK components in an explanation. Secondly, there was an emergence of sophisticated TSPCK episodes in the actual classroom teaching. The clustering of TSPCK episodes was also observed where episodes of different categories appeared to work together in building up an explanation. The intention seen in the plTSPCK episodes was retained in the delivered lesson. An increase in TSPCK clustering was further prompted by the teacher-learner interactions, through the learners' responses or questions that needed clarity.

The response to this question is:

The quality of PGCEs enacted TSPCK as described by the constructed teacher TSPCK profiles, showed increased quantities of proficient and sophisticated eTSPCK episodes that fall in the higher

quality categories of the rubric used in this study. This signaled the presence of high quality TSPCK episodes in each of the pre-service teachers' lessons.

Research question 3:

The third research question examined the relationship that the PPSTs' eTSPCK observed in their classroom teaching of Chemical Equilibrium had to the learner conceptual performance. The question was:

In what ways does the observed PGCE's enacted TSPCK observed in the classroom relate to the learner performance in Chemical Equilibrium?

First, the performances of the learners prior to the teachings by the PPSTs was established as a reference point through which the knowledge gain can be calculated following the PPSTs' teaching of Chemical Equilibrium. The correlation test then followed to determine the relationship between the PPSTs' eTSPCK and the learner performance in the pre-and post-achievement tests. The findings revealed that the presence of a statistically significant improvement was observed in the learner performance test, with an average of 75% following the PPSTs' teaching of Chemical equilibrium. Additionally, a high correlation between the PPSTs' overall eTSPCK episodes and learner post-test performance in Chemical Equilibrium was established. Finally, a high correlation was found to have a positive value indicating a direct relationship between sophisticated eTSPCK episodes and learner performances in the post-test following the teachings by the PPSTs.

The three research questions provided adequate findings enabling the formulation of a response for the main research question guiding this study as follows:

The explicit discussions of content-specific components of TSPCK on a topic of Chemical Equilibrium, which equipped the PPSTs with pedagogical transformation competence, influenced the quality of the PPSTs' personal TSPCK seen in their planning to teach as plTSPCK and enactment level (eTSPCK)as observed in their actual classroom teaching of Chemical Equilibrium. The PPSTs' plTSPCK improved from a lower limited TSPCK category to a higher developing TSPCK category following the intervention, while their teaching was dominated by proficient and sophisticated eTSPCK episodes. A positive and high correlation between the PPSTs' eTSPCK episodes and learner performances in the post-test suggest a strong direct

correlation between the PPST's TSPCK and the gain in the knowledge observed in learner performance in the post-test.

9.4. Conclusion

The study aimed at providing an insight into the PCK literature on how the intervention that aimed at developing the PGCE PSTs' TSPCK when planning to teach translates into classroom teaching and how this influences learner achievement. This view emanated from the reported consensus that PCK can be examined through planning by investigating what a teacher knows and how they are able to do what they know which can only be observed in the actual classroom teaching of specific topics (Mavhunga & van der Merwe, 2020; Aydin, *et al.*, 2015). This study was intuitively linked to the challenge of the recurring issue of the theory-practice gap which has been challenging in education researchers (Mavhunga & van der Merwe, 2020; Barradell & Kennedy-Jones, 2015; McDonald *et al.,* 2013). Central to this problem is the acknowledgement of the dissonance between knowledge acquired through planning to teach, and the actual teaching of content in the classroom (Mavhunga & van der Merwe, 2020). Pedagogical content knowledge (PCK), particularly topic-specific pedagogical content knowledge (TSPCK), has been proven in this study as a theoretical construct that offers an opportunity to the science educators to bridge the theory-practice divide with the aim of improving learner achievement in science topics.

The findings in this study have supported the claim in the literature on the topic specific nature of PCK, and how the quality of a teacher's PCK in a specific topic can be used as a determining factor of learner outcomes in that particular topic (Förtsch *et al*., 2016; Akinyemi, 2020). This study concludes by appreciating the advantage in the qualitative and quantitative ways accrued to developing the PPSTs' TSPCK for planning to teach a specific physical science topic, as seen in the planning and actual classroom teaching with a positive influence on learner performance.

9.5. Implications and recommendations of the study

In this section, I provide implications and the recommendations of this study within a South African context. Although this study was conducted within a specific case of physical science PGCE pre-service teachers, and the findings can, therefore, not be generalized; the following implications are made to the science education community and pre-service teacher preparation programmes, specifically the PGCE pre-service teachers.

- ***Implications for the science education research community***

1. The findings in this study have added to the empirical evidence justifying the topic specific nature of PCK described from various content-specific components that constitute PCK. The idea of exploring the topics one after the other, using a TSPCK construct has a promise for understanding the nature of PCK from using the content-specific components for pedagogical transformation content knowledge of a topic.
2. By exploring the link between the PPSTs' TSPCK and learner outcomes for a specific topic, this study has validated the Refined Consensus Model (RCM) of PCK that suggested a cPCK-pPCK-ePCK-learner outcomes continuum link by providing the empirical findings that confirm this link.
3. This study has also added to the empirical evidence that established a relationship between the teachers' high TSPCK quality and high learner performances. This contributed to the literature that reports on the existence of a positive relationship between PCK and learner outcomes, and thus a solid base for exploring further research for the casual-effect link.

- ***Implications of the study for the PGCE science teacher education programmes***

i. The findings in Chapter 5 indicated that PCK within a topic can be improved significantly in PGCE pre-service teachers (PPSTs). The PPSTs' TSPCK of any topic can be improved by emphasizing the interactive use of content-specific components of pedagogical transformation of content knowledge. This understanding was seen in the PPSTs' explanations presented in the post-TSPCK tool and CoRe tool which demonstrated the application of the competence learned in the intervention. The study recommends that the TSPCK construct should be included in teacher preparation programmes and more specifically in the preparation of PGCE PSTs. The findings have the potential to benefit teacher preparation in South Africa and other developing countries in Africa, where there is a high shortage of skilled and knowledgeable science teachers.

ii. The findings in Chapter 6 showed the transfer of competence by the PPSTs, revealed through the interactive use of content specific TSPCK components in their actual classroom teaching of Chemical Equilibrium. The PPSTs' teaching was dominated by TSPCK episodes of high quality, largely categorized at proficient and sophisticated TSPCK levels. In the end, the quality of the PPSTs' enacted TSPCK was similar to

their planned TSPCK, following the explicit discussions that emphasized the interactive use of multiple content-specific components when transforming content knowledge in Chemical Equilibrium. The study thus recommends the inclusion of this construct in teacher education programmes to bridge the theory-practice divide for newly prepared teachers.

iii. The findings in Chapter 7 revealed an improvement in the learners' post-achievement test performances following the PPSTs' teachings. Chapter 8 also revealed a significant positive correlation between the PPSTs' enacted TSPCK and learner performances in the post-test. The strength in correlation was found to increase with higher quantities of sophisticated TSPCK episodes. It is therefore recommended that PGCE pre-service teacher education programmes give priority to including the TSPCK construct in their programme, to develop the teachers' competence in transforming content in the form that the learners can efficiently understand.

iv. The findings in Chapter 8 showed that the learners' performance and understanding of the concepts is driven by the PPSTs' use of representations, giving real-life examples and emphasis of important concepts. This discovery confirms the importance of knowledge of content specific TSPCK components and their interactive use to provide the meaningful nuance of a concept.

This study has shown that the PGCE programmes (short as the programme is) have the potential to affect the quality of the teachers' topic specific PCK for teaching science. By introducing the TSPCK construct in PGCE teacher training programmes, the PPSTs are likely to exit the programme with pedagogical transformation competence to reason through any topic content into a form more compressible by the learners. This can help to fast-track the ability of the PPSTs to deliver sound lessons on entry into the classroom. Growing their competence to teach for understanding is likely to positively impact on student achievement, and thus improve the performance of the learners in South African schools.

9.6. Critical reflections of the research process

9.6.1 Collective TSPCK: Reflection on the intervention

As discussed in the previous sections, several studies have employed the same intervention using a TSPCK construct as the framework anchoring the intervention. Although the prime focus of this

study was not necessarily the intervention, the aim was to create a credible baseline from which the link between TSPCK and learner achievement would be interpreted. The first observation that was made was the importance of maintaining the purpose of the study throughout the weeks of running the intervention. For this reason, each session would begin with a recap of what the purpose of the intervention was, which aimed to develop their ability to pedagogically transform content knowledge of Chemical Equilibrium into a teachable form that can efficiently be accessed by the learners and how this can be done. These opening reflections made it possible for the connections to be made between the sessions even though the aspects discussed were different for each session. The observations are consistent with the previous research that there is benefit in raising the PSTs' awareness of PCK as the knowledge they themselves are acquiring and in the processes, they are undertaking (Mavhunga, 2012; Akinyemi, 2020). In some instances, the PPSTs would ask questions related to the previous lessons which proved the relatedness between the TSPCK components being discussed.

Second, the explicit nature of the session discussions was an efficient approach of exposing the PPSTs' to the TSPCK construct. This enabled them and the researcher to engage through a mix of explanations, questions and responses. Through these engagements and discussions, the PPSTs and the researcher witnessed a development in understanding as each session unfolded. Some of these instances which revealed a development in the understanding of the construct have been presented in chapter 4 which described the actual intervention process in detail. The learning environment in the classroom was always welcoming and did not have any signs of hostility. Any cases of disruptions from the PPSTs' were strongly discouraged and such moments were not recurrent because of a small number of PPSTs in the class (a total of 8). In most cases, I had to move back and forth, repeating concepts because the PPSTs were struggling to understand. This was the case mostly because the PPSTs are not taught content knowledge in their programme. They are only taught the pedagogy of teaching the content. This is because of the assumption that they already have content in place from their previously acquired bachelor's degrees. This resulted in the discussions taking longer than anticipated as the purpose was to also ensure that the PPSTs understood the topic content since content knowledge is regarded as the precursor to developing knowledge for teaching (Pitjeng-Mosabala & Marissa, 2018). As overwhelming as some sessions were, with the assistance of one of the experienced teacher educators who delivered most of the methodology courses, the discussions were always very interesting and fulfilling.

9.6.2. Reflections on the research methodology used

Of great interest in this study was to understand the TSPCK-learner achievement continuum link for a group of PPSTs, following the exposure to the TSPCK construct that aimed at developing their knowledge for teaching Chemical Equilibrium. The study employed a mixed method approach through the use of both qualitative and quantitative processes. The benefits of using a mixed method approach included helping one to understand and reflect on the complexity of the phenomenon and to developing new knowledge through the synthesis of the findings emerging from different research approaches (Creswell & Clark, 2017). The use of a mixed method approach in this study assisted me with capturing and portraying the PPSTs' TSPCK which is understood to be complex. The discussions below provide reflections on the cases where the mixed method approach became beneficial.

First the study utilized an in-depth qualitative analysis to explain the quality and development of the PPSTs' planned TSPCK, captured through intervention discussions as well as the written explanations during and after the intervention. Thus, qualitative approaches assisted the study with capturing pedagogical constructive processes as they manifested verbally and from written explanations provided by the PPSTs. The pre-and post-intervention TSPCK tests were quantitatively processed to confirm the improvement in the PPSTs' TSPCK following the intervention. The quantitative scores were interpreted qualitatively to understand the degree and quality of TSPCK development. The qualitative approaches were also suitable for examining the application of PPSTs' understanding of the interactive use of content-specific TSPCK components, acquired during the intervention, in completing content representations (CoRes) on the same topic of intervention, Chemical Equilibrium. The findings of this analysis acted as a credible baseline from which the eTSPCK-learner achievement link was examined.

Similarly, an in-depth qualitative analysis was employed to describe the PPSTs' enacted TSPCK which involved capturing and portraying their interactive use of content-specific components in their teaching of Chemical Equilibrium portrayed in TSPCK episodes. This was a mini-case study of 3 PPSTs derived from a cohort of 8 PPSTs that participated in the intervention. The use of a case study as an approach facilitated an in-depth exploration of the PPSTs' eTSPCK, considering the complexity of the actual classroom teaching and learning. The interpretation of identified eTSPCK episodes involved categorization, using an eTSPCK rubric that classifies episodes into

different levels of TSPCK episodes and visually presented into TSPCK maps. To help describe how different TSPCK episodes build onto each other to explain concepts, the episodes were then visually presented in the order of their emergence in the lesson. The revealed extent of the interactive use of TSPCK components when teaching Chemical Equilibrium concepts signaled the quality of the PPSTs' eTSPCK.

The findings from this qualitatively analyzed data were useful for determination of the TSPCK-learner achievement link. Through the use of quantitative approaches, the learners' achievement tests were analyzed, and the extent of the significant difference determined with the focus being on the learners' pre-and post-test scores. This provided an understanding about the learners' conceptual performance and the level of engagement on the test items prior to and following the PPSTs' teaching. Statistical analysis also assisted the researcher to determine the correlation between the PPSTs' TSPCK and learner achievement in Chemical Equilibrium by revealing the strength and direction of the correlation. Following this was the use of qualitative approaches which allowed the examination of the relationship between the quality of TSPCK episode and the learner performance gains and quality of written responses in the pre-and post-achievement tests. While quantitative approaches provided the strength and direction of the correlation, qualitative patterns complemented this by revealing the weakness or strength of interactions among TSPCK components. This was an indication of high or weak correlations to learner performances. Consequently, the use of a mixed methods approach enabled the correlation analysis to be done using both qualitative and quantitative approaches. Through the convergence of the two approaches, the study successfully examined the nature of the relationship between the PPSTs' eTSPCK and learner performances.

Furthermore, while the use of a case study research approach allowed for an in-depth exploration from small samples, one of the disadvantages is that the findings cannot be generalized. For this particular study, a total of 8 PPSTs formed a larger case that was exposed to the intervention and had their plTSPCK examined. From this cohort, 3 PPSTs formed mini cases from which the eTSPCK was explained and correlation with learner performances established. The study acknowledges the limitation of the sample which restricts the generalization of the findings.

9.6.3. Validity and Trustworthiness

The superiority of a mixed method research design over a single design includes the fact that it allows for a greater understanding of a phenomenon being studied by offering detailed information that might be missed when using only one research design and it results in more reliable and relevant findings (Caruth, 2013; Cronholm & Hjalmarsson, 2011).Furthermore, the quality of mixed method research studies is generally determined by the quality of each of the qualitative and quantitative strands. As argued by Teddie and Tashakkori (2009), "if the data of the individual strands is valid and credible, then the mixed study will have a high overall data quality" (p. 209). The observation of different standards in the assessment of the quality of data collected through the respective research approaches reflects the overall quality of data in this study. Some of the practices that have been reported to enhance data quality have been provided at various points in the discussion above and reported extensively in Chapter 3. Examples of such practices included using various data collection strategies such as pre-and post-TSPCK tests, Content Representations (CoRes), on-going tutorial presentations, videorecording of classroom teaching and respective collection of the lesson plans, conducting pre-and post-lesson and stimulated-recall interviews, learner pre-and post-achievement tests and the collection of the learners' views. This reduced my own bias as a researcher and thus enhanced the credibility of the research findings. An involvement of a team of experienced independent raters, who assisted in analyzing the completed TSPCK test tools and TSPCK episodes from the video recorded lessons as well as in scoring the identified episodes and the learners' pre-and post-achievement tests was to ensure the trustworthiness of the findings of this study.

9.7. Limitations of the study

This study acknowledges the presence of a few critical limitations. Firstly, the study was a case of eight PPSTs that examined planned TSPCK which was captured before and after the intervention. Three out of this class of 8 PPSTs were used as mini-cases and their enacted TSPCK captured when teaching Chemical Equilibrium. The small sample sizes for this study means that the findings cannot be generalized but can possibly be considered for other groups of PPSTs. Secondly, the absence of a control group (for teaching) and the records of the PPSTs' teaching of the same topic prior to the intervention makes it **difficult** to claim that all that was observed in their teaching was exclusively the result of the intervention. Thirdly, the tacit and complex nature of PCK also means

that the classroom observations made of the PPSTs teaching Chemical Equilibrium, with the focus on the interactive use of TSPCK components, may have portrayed their PCK only partially (Alonzo *et al*., 2012; Aydin *et al*., 2014). For this reason, the study does not, in any way claim, to have captured all the aspects of the PPSTs' eTSPCK, although efforts were made to portray the TSPCK seen in the classroom teaching. Furthermore, the study acknowledges that the use of video recording of the lessons may have affected the behavior of both the PPSTs and the learners, thus causing bias. The use of independent raters to assist with the analysis multiple follow-up interviews and in-depth approaches of analysis also assisted with alleviating this bias.

Nevertheless, this study has provided empirical evidence that an introduction of the TSPCK framework in the teacher training has the potential of fast-tracking the development of the PSTs' TSPCK in the context of learning to teach (Mavhunga & Rollnick, 2013). Also important was the need to emphasize the interactive use of TSPCK components to develop PPSTs' plTSPCK and eTSPCK and ultimately make an impact on learner outcomes. Remarkably, even with a limited time of exposure to the TSPCK framework, the PGCE pre-service teachers' TSPCK improved, following the intervention. This study has therefore provided some insights about the benefits of influencing the educational policy on initial teacher training to have programmes that focus on the TSPCK construct in order to improve science teaching and, ultimately, learner outcomes.

9.8. Future Research

This study has firstly shown that the quality of the PPSTs' planned TSPCK may be improved by explicit discussions that focus on the TSPCK components needed to pedagogically transform the content knowledge of a given topic. Secondly, the study revealed that the pedagogical transformation competence learnt by the PPSTs during the intervention in the context of planning to teach Chemical Equilibrium was evident in the PPSTs' actual classroom teaching of Chemical Equilibrium. This study also revealed that the enacted TSPCK observed in the actual teaching of content in the classroom can be positively linked to the learner outcomes. As explained earlier, the findings on planned TSPCK emerged first from a cohort of 8 PPSTs, whilst that on eTSPCK emerged from a subset of 3 PPSTs. It is therefore necessary to conduct further research that involves a larger sample to show how an exposure to explicit discussions on topic specific PCK development of core science topics influence the planned and enacted TSPCK of PPSTs in relation to learner outcomes. This also includes the need for large scale studies that explore the causal-

effect link. Further research with the PPSTs that involves the transferability of the learnt pedagogical transformation competence (similar to Mavhunga *et al.*, 2016) into other chemistry topics is also necessary. In developing countries such as South Africa, where teacher education and learner performance in science are challenging issues, a large-scale research focusing on the effect of this TSPCK construct may generate useful information for improving pre-service science teacher education programmes, the quality of instruction in schools and ultimately learner outcomes.

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.

Adadan, E., & Oner, D. (2014). Exploring the Progression in Preservice Chemistry Teachers ' Pedagogical Content Knowledge Representations : The Case of " Behavior of Gases ." *Research in Science Education*, 44, 829–858. https://doi.org/doi.org/10.1007/s11165-014-9401-6

Ajjawi, R. & Boud, D. (2017). Researching feedback dialogue: an interactional analysis approach. *Assessment & Evaluation in Higher Education*, 42(2), 252–265.

Akinyemi, O. S. (2020).*Exploring The Development Of Pre-Service Teachers' Topic Specific Pck And Its Influence On Learner Outcomes* (Doctoral Thesis). University of the Witwatersrand, Johannesburg South Africa.

Aldrich, J. (2018). Using IBM® SPSS® Statistics: *An interactive hands-on approach*(2nd ed.). Thousand Oaks, CA: SAGE.

Alonzo, A., Berry, A., & Nilsson, P. (2019). Unpacking the Complexity of Science Teachers' PCK in Action: Enacted and Personal PCK. In A. Hume, R. Cooper, & A. Borowski (Eds.),*Repositioning Pedagogical Content Knowledge in Teachers' Knowledge for Teaching Science* (pp. 271–286). Singapore, Springer.

Al-Sharif, E. M. (2010). Evaluation of Student / Teacher Teaching Competencies in the Curricula and Teaching Methods of Motor Expression in the Light of Quality Academic Standards. *World Journal of Sport Sciences*, 3, 331-358.

Amelia, R., Handayanto, S., & Muhardjito, M. (2016). The Influence of V Diagram Procedural Scaffolding in Group Investigation Towards Students with High and Low Prior Knowledge. *Journal Pendidikan IPA Indonesia*, 5(1), 108–115.

Asan, O., & Montague, E. (2014). Using video-based observation research methods in primary care health encounters to evaluate complex interactions. *Inform Prim Care*, 21(4), 161–170. doi:10.14236/jhi.v21i4.72.

Aydeniz, M., & Kirbulut, Z. (2014). Exploring challenges of assessing pre-service science teachers' pedagogical content knowledge (PCK). *Asia-Pacific Journal of Teacher Education*, 42(2), 147–166.

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. https://doi.org/doi.org/10.1039/c3rp00095h

Aydin, S., Demirdogen, B., Akin, F. N., Uzuntiryaki-Kondakci, E., & Tarkin, A. (2015). The nature and development of interaction among components of pedagogical content knowledge in practicum. *Teaching and Teacher Education*, 46, 37–50.

Aydin, S., Friedrichsen, P., Boz, Y., & Hanuscin, D. (2014). Examination of the topic-specific nature of electrochemical cells and nuclear reactions. *Chemistry Education Research and Practice*, 15, 658–674. https://doi.org/doi.org/10.1039/C4RP00105B

Ball, D., & Forzani, F. (2009). The work of teaching and the challenge for teacher education. *Journal of Teacher Education*, 60(5), 497–511.

Banerjee, A. C., & Power, C. N. (1991). The development of modules for the teaching of chemical equilibrium. *International Journal of Science Education*, 13 (3), 355-362. DOI: 10.1080/0950069910130312

Barradell, S., & Kennedy-Jones, M. (2015). Threshold concepts, student learning and curriculum: making connections between theory and practice. *Innovations in Education and Teaching International*, 52(5), 536–545.

Barth, P., Dillon, N., Hull, J., & Higgins, H. (2016). *Fixing the holes in the teacher pipeline: An overview of teacher shortages*. Center for Public Education. Retrieved from http://www.centerforpubliceducation.org/system/files/Teacher%20Shortage_0.pdf.

Baskarada, S. (2014). Qualitative case study guidelines. *The qualitative Report*, 19(40), 1-18. Retrieved from http://nsuworks.nova.edu.tqr/voliq/iss40/3

Bayaga, A. (2010). Statistics and probability education in South Africa: Constraints of learning.*Problems of Education in the 21st Century*, 20, 25-35.

Baxter, J., & Lederman, N. (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: Springer.

Benesty, J., Chen, J., & Huang, Y. A. (2008). On the Importance of the Pearson Correlation Coefficient in Noise Reduction. *IEEE transactions on audio, speech, and language processing*,16(4), 757-765.

Ben-Zvi, R., Eylon, B., & Silberstein, J. (1987). Students' visualization of a chemical reaction. *Education in Chemistry*, 24, 117-120.

Bergquist, W., & Heikkinen, H. (1990). Student ideas regarding chemical equilibrium. *Journal of Chemical Education*, 67, 1000- 1003.

Bertram, A., & Loughran, J. (2012). Science teachers' views on CoRes and PaP-eRs as a framework for articulating and developing pedagogical content knowledge. *Research in Science Education*, 42(6), 1027–1047.

Bertram, A., & Loughran, J. (2014). Planting the seed: Scaffolding the PCK development of preservice science teachers. In H. Venkat, M. Rollnick, J. Loughran& M. Askew (Eds.),*Exploring mathematics and science teachers' knowledge: Windows into teacher thinking* (pp. 117–131). Abingdon: Routledge.

Bertram C, Mthiyane, N.,& Mukeredzi, T.(2013). 'It will make me a real teacher': learning experiences of part time PGCE students in South Africa. *International Journal of Educational Development*, 33(5):448-456.

Bilgin, I. (2006b). Promoting Pre-Service elementary students' understanding of chemical equilibrium through discussions in small groups. *International Journal of Science and Mathematics Education*, 4(3), 467-484.

Bilgin, I., Uzuntiryaki, E., & Geban, Ö. (2003). Student's Misconceptions on the Concept of Chemical Equilibrium. *Education and Science*, 28 (127), 10-17.

Blömeke, S., Olsen, R. V., & Suhl, U. (2016). Relation of student Achievement to the quality of their teachers and instructional quality. In T. Nilsen & J. E. Gustafsson (Eds.), *Teacher Quality, Instructional Quality and Student Outcomes* (pp. 21-50). Cham, Springer.

Bond, T. & Fox, C. (2015). Applying the Rasch model, (3rded.). New York and London.Routledge, Taylor & Francis Group.

Boone, W., Staver, J., & Yale, M. (2014). Rasch analysis in the human sciences. Dordrecht, the Netherlands: Springer.

Brooks, J. S., & Normore, A. H. (2015). Qualitative research and educational leadership, *International Journal of Educational Management*, 29 (7), 798 – 806. http://dx.doi.org/10.1108/IJEM-06-2015-0083

Brunce, D. M.,&Gabel, D. L. (2002). Differential effects on the achievement of males and females of teaching the particulate nature of chemistry. *Journal of Research in Science Teaching*, 39, 911–927.

Callingham, R., Carmichael, C., & Watson, J. (2016). Explaining student achievement: The influence of teachers' pedagogical content knowledge in statistics. *International Journal of Science and Mathematics Education,* 14(7), 1339–1357.

Carlson, J., & Daehler, K. R. (2019). The refined consensus model of pedagogical content knowledge in science education. InA. Hume, R. Cooper, & A. Borowski (Eds.),*Repositioning pedagogical content knowledge in teachers' knowledge for teaching science* (pp. 77-92). Singapore , Springer.

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. 24–37). Abington: Routledge.

Carpendale, J., & Hume, A. (2019). Investigating practicing science teachers' pPCK and ePCK development as a result of collaborative CoRe design. In A. Hume, R. Cooper, & A. Borowski (Eds.),*Repositioning pedagogical content knowledge in teachers' knowledge for teaching science* (pp. 223-250). Singapore, Springer.

Caruth, G. (2013). Demystifying mixed methods research design: A review of the Literature. *Mevlana International Journal of Education* (MIJE), 3(2), 112–122.

Chan, K., & Hume, A. (2019). Towards a consensus model: Literature review of how science teachers' pedagogical content knowledge is investigated in empirical studies. InA. Hume, R. Cooper, & A. Borowski (Eds.),*Repositioning pedagogical content knowledge in teachers' knowledge for teaching science* (pp. 3–76). Springer, Singapore.

Chan, K., & Yung, B. (2015). On-site pedagogical content knowledge development. *International Journal of Science Education*, 37(8), 1246–1278.

Chan, K., & Yung, B. (2018). Developing pedagogical content knowledge for teaching a new topic: more than teaching experience and subject matter knowledge. *Research in Science Education*, 48(2), 233–265.

Chordnork, B., & Yuenyong, C. (2014). Constructing CoRe as a Methodological for Capturing Pedagogical Content Knowledge: A Case Study of Thailand Teachers Teaching Global Warming. *Procedia - Social and Behavioral Sciences, 116*(0), 421-425. doi:http://dx.doi.org/10.1016/j.sbspro.2014.01.233

Cochran, K. F, King, R. A.,& DeRuiter, J. A. (1991). *Pedagogical Content Knowledge: aTentative Model for Teacher Preparation*. East Lansing, MI: National Center for Research on Teacher Learning. (ERIC document reproduction service no). ED340683).

Cooper, R., Loughran, J., & Berry, A. (2015). Science teachers' PCK: Understanding sophisticated practice. InIn A. Berry, P. Friedrichsen & J. Loughran (Eds.). *Re-examining pedagogical content knowledge in science education* (pp. 70–80). Abington: Routledge.

Cope, D. (2014). Methods and meanings: credibility and trustworthiness of qualitative research. *Oncology Nursing Forum*, 41(1), 89–91.

Creswell, J. (2012). Education Research: Planning, Conducting and Evaluating Quantitative and Qualitative Research (4th ed.).Boston, MA: Pearson Education.

Creswell, J. (2014). Research Design: Qualitative, Quantitative and Mixed Methods Approaches (4th ed.). Thousand Oaks, CA: Sage.

Creswell, J., & Clark, P. (2017). Designing and Conducting Mixed Methods Research (2nd ed.). Thousand Oaks, CA: Sage.
Cronholm, S., & Hjalmarsson, A. (2011). Experiences from Sequential Use of Mixed Methods. *The Electronic Journal of Business Research Methods,* 9 (2), 87-95.
Cross, D., & Lepareur, C. (2015). PCK at Stake in Teacher–Student Interaction in Relation to Students' Difficulties. In *Understanding Science Teachers' Professional Knowledge Growth* (pp. 47–61). Sense Publishers.
Davidowitz, B., Chittleborough, G., & Murray, E. (2010). Student-generated submicro diagrams: a useful tool for teaching and learning chemical equations and stoichiometry, 154-164. https://doi.org/10.1039/C005464J
Davidowitz, B., & Potgieter, M. (2016). Use of the Rasch measurement model to explore the relationship between content knowledge and topic-specific pedagogical content knowledge for organic chemistry. *International Journal of Science Education,* 38(9), 1483–1503.
Davidowitz, B., & Vokwana, N. (2014). Developing an instrument to assess Grade 12 teachers' TSPCK in organic chemistry. Exploring Mathematics and Science Teachers' Knowledge: *Windows into Teacher Thinking*, 178–194.
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, 947–964.
Department of Higher Education and Training. (2015). National Qualifications Framework Act (67/2008): Revised policy on the minimum requirements for teacher education qualifications. Government Gazette, 596, 1–72.
Dumez, H. (2015). What is a case, and what is a case study? *Bulletin of Sociological Methodology*, 127 (1), 43–57.
Dutro, E., & Cartun, A. (2016). Cut to the core practices: Toward visceral disruptions of binaries in PRACTICE-based teacher education. *Teaching and Teacher Education,* 58, 119-128
Evens, M., Elen, J., Larmuseau, C., & Depaepe, F. (2018). Promoting the development of teacher professional knowledge: Integrating content and pedagogy in teacher education. *Teaching and Teacher Education*, 75, 244–258.
Ferguson, R., & Bodner, G. (2008). Making sense of the arrow-pushing formalism among chemistry majors enrolled in organic chemistry. *Chemistry Education Research and Practice,* 9(2), 102–113.
Fernández-Balboa, J., & Stiehl, J. (1995). The generic nature of pedagogical content knowledge among college professors. *Teaching and Teacher Education*, 11(3), 293–306.
Findlay, M., & Bryce, T. G. K. (2012). From teaching physics to teaching children: Beginning teachers learning from pupils, *International Journal of Science Education,* 34(17), 2727-2750.
Fisher, G., & Scott, I. (2011). Closing the Skills and Technology Gap in South Africa-Background paper 3: The Role of Higher Education in Closing the Skills Gap in South Africa.*The World Bank, Human Development Group*, 1–56. Africa. (October). https://pdfs.semanticscholar.org/2879/4915e2fb0e9841917110005d963f5bc456a1.pdf?_ga=2.121838466.841110602.1584451405-1583425823.1584102331
FitzGerald, E. (2012). *Using Augmented Reality for Mobile Learning: Opportunities and Challenges*. Workshop Proceedings: Mobile Augmented Reality for Education. Helsinki, Finland, 2-5.

Förtsch, C., Werner, S., Von-Kotzebue, L., & Neuhaus, B. (2016). Effects of biology teachers' professional knowledge and cognitive activation on students' achievement. *International Journal of Science Education*, 38(17), 2642–2666.

Friedrichsen, P., Abell, S. K., Pareja, E. M., Brown, P. L., Lankford, D. M., & Volkmann, M. J. (2009). Does teaching experience matter? Examining biology teachers' prior knowledge for teaching in an alternative certification program. *Journal of Research in Science Teaching*, 46(4), 357–383.

Geddis, A. (1993). Transforming subject-matter knowledge in learning to reflect on teaching. *International Journal of Science Education*, 15(6), 673–683.

Geddis, A. N, Onslow, B., Beynon, C., & Oesch, J. (1993). Transforming content knowledge: Learning to teach about isotopes. *Science Education*, 77(6), 575–591.

Geddis, A., & Wood, E. (1997). Transformation of subject matter and managing dilemmas: A case study in teacher education. *Teaching and Teacher Education*, 13(6), 611–626.

Geddis, Arthur N., & Wood, E. (1997). Transforming subject matter and managing dilemmas: A case study in teacher education. *Teaching and Teacher Education*, 13(6), 611–626. https://doi.org/10.1016/S0742-051X(97)80004-2

Gess-Newsome, J. (2015). A model of teacher professional knowledge and skill including PCK: Results of the linking from the PCK Summit. In *Re-examining Pedagogical Content Knowledge in Science Education* (pp. 28–42). London: Routledge.

Gess-Newsome, J., Taylor, J. A., Carlson, J., Gardner, A. L., Wilson, C. D., & Stuhlsatz, M. A. (2019). Teacher pedagogical content knowledge, practice, and student achievement. *International Journal of Science Education*, 41(7), 944–963.

Ghirardi, M., Marchetti, F., Pettinari, C., Regis, A., & Roletto, E. (2015). Implementing an Equilibrium Law Teaching Sequence for Secondary School Students to Learn Chemical Equilibrium. *Journal of Chemical Education*, 92, 1008-1015.

Gottheiner, D. M., & Siegel, M. A. (2012). Experienced Middle School Science Teachers' Assessment Literacy: Investigating Knowledge of Students' Conceptions in Genetics and Ways to Shape Instruction. *Journal of Science Teacher Education*, 23, 531–557 DOI 10.1007/s10972-012-9278-z

Greasley, P. (2007). Quantitative data analysis using SPSS: an introduction for health & social science. McGraw-Hill Education (UK).

Grossman, P. L. (1990). *The Making of a Teacher: Teacher Knowledge and Teacher Education*. New York: Teachers College Press.

Grossman, P., Hammerness, K., & McDonald, M. (2009). Redefining teaching, re-imagining teacher education, *Teachers and Teaching: theory and practice*, 15(2), 273-289.

Guba, E. G. (1981). Criteria for assessing the trustworthiness of naturalistic inquiries. *Educational Communiction and Technology Journal*, 29, 75-92.

Gustafsson, J., & Nilsen, T. (2016). The impact of school climate and teacher quality on mathematics achievement: A difference-in-differences approach. *Teacher Quality, Instructional Quality and Student Outcomes*, 2, 81–95.

Guzey, S., & Roehrig, G. (2009). Teaching science with technology: case studies of science teachers' development of technological pedagogical content knowledge (TPCK). *Contemporary Issues in Technology and Teacher Education*, 9(1), 25–45.

Halcomb, E. J., & Hickman, L. (2015). Mixed methods research. *Nursing Standard: promoting excelence in nursing care*, 29 (32), 41-47.

Halim, L., Abdullah, S., & Meerah, T. (2014). Students ' Perceptions of Their Science Teachers ' Pedagogical Content Knowledge. *Journal of Science Education and Technology*, 23(2), 227–237. https://doi.org/doi.org/10.1007/s10956-013-9484-2

Halim, L.,& Meerah, S. M. (2002). Science trainee teachers' pedagogical content knowledge and its influence on physics teaching, *Research in Science and Technological Education,* 20(2), 215-225.

Harrison, A. G., & De Jong, O. (2005). Exploring the Use of Multiple Analogical Models When Teaching and Learning Chemical Equilibrium. *Journal of Research in Science Teaching*, 42 (10), 1135–1159.

Heale, R., & Twycross, A. (2015). Validity and reliability in quantitative studies. *Evidence Based Nursing*, 18 (3), 66-68.

Helmke, A. (2014). Unterrichtsqualität und Lehrerprofessionalität [Instructional quality and teachers' professional competence]. Seelze-Velber, Klett/Kallmeyer.

Henze, I., & Barendsen, E. (2019). Unravelling student science teachers' pPCK development and the influence of personal factors using authentic data sources. In A. Hume, R. Cooper, & A. Borowski (Eds.),*Repositioning pedagogical content knowledge in teachers' knowledge for teaching science* (pp. 201–221). Singapore, Springer.

Henze, I., & Van Driel, J. (2015). Toward a more comprehensive way to capture PCK in its complexity. In *Re-examining Pedagogical Content Knowledge in Science Education* (pp. 130–144). Routledge.

Henze, I., Van Driel, J., & 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.

Hinkle, D., Wiersma, W., & Jurs, S. (2003). Applied Statistics for the Behavioral Sciences. Boston: Houghton Mifflin College Division.

Hirst, H. P. (1980). The PGCE course and the training of specialist teachers for secondary schools, *British Journal of Teacher Education*, 6:1, 3-20, DOI: 10.1080/0260747800060102

Hodgson, J. (2014). Surveying the wreckage: the professional response tochanges to initial teachertraining in the UK.*English in Education*, 48 (1), 7-25.

Howie, S. J., Van Staden, S., Tshele, M., Dowse, C., & Zimmerman, L. (2012). PIRLS 2011: *SouthAfrican Children's ReadingLiteracy Achievement SummaryRreport.* Pretoria: Centre forEvaluation and Assessment.

Huddle P. A., White, M. W.,& Rogers F. (2000), Simulations for teaching chemical equilibrium.*Journal of Chemistry Education.*, 77, 920-926

Hume, A., & Berry, A. (2011). Constructing CoRes—A strategy for building PCK in pre-service science teacher education. *Research in Science Education*, 41(3), 341–355.

Hume, A., & Berry, A. (2013). Enhancing the Practicum Experience for Pre-service Chemistry Teachers Through Collaborative CoRe Design with Mentor Teachers. *Research in Science Education*, 43, 2107–2136. https://doi.org/doi.org/10.1007/s11165-012-9346-6

Ingersoll, R., & Perda, D. (2009). The Mathematics and Science Teacher Shortage: Fact and Myth. Philadelphia: Consortium for Policy Research in Education, University of Pennsylvania.

Jewitt, C. (2012). An Introduction to Using Video for Research (Working Paper). National Centre for Research Methods. Southampton, UK.

Jüttner, M., Boone, W., Park, S., & Neuhaus, B. (2013). Development and use of a test instrument to measure biology teachers' content knowledge (ck) and pedagogical content knowledge (pck). *Educational Assessment, Evaluation and Accountability*, 25(1), 45–67.
Kagan, D. M. (1990). Ways of evaluating teacher cognition: inferences concerning the goldilocks principle. *Review of Educational Research*, 60(3), 419–469.
Kambouri, M. (2016). Investigating early years teachers' understanding and response to children's preconceptions, *European Early Childhood Education Research Journal*, 24:6, 907-927, DOI: 10.1080/1350293X.2014.970857
Kaya, O. (2009). The nature of relationships among the components of pedagogical content knowledge of preservice science teachers:'Ozone layer depletion'as an example. *International Journal of Science Education*, 31(7), 961–988.
Keller, M., Neumann, K., & Fischer, H. (2017). The impact of physics teachers' pedagogical content knowledge and motivation on students' achievement and interest. *Journal of Research in Science Teaching*, 54(5), 586–614.
Kind, V. (2009). Pedagogical content knowledge in science education : perspectives and potential for progress 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.
Kind, V., & Chan, K. (2019). Resolving the amalgam: connecting pedagogical content knowledge, content knowledge and pedagogical knowledge. *International Journal of Science Education*, 41(7), 964–978.
Kirschner, S., Borowski, A., Fischer, H., Gess-Newsome, J., & Von-Aufschnaiter, C. (2016). Developing and evaluating a paper-and-pencil test to assess components of physics teachers' pedagogical content knowledge. *International Journal of Science Education*, 38(8), 1343–1372.
Kousathana, M., & Tsaparlis, G. (2002). Students' error in solving numerical chemical equilibrium problems. *Chemistry Education. Research and Practice in Europe*, 3, 5-17.
Kunter, M., Klusmann, U., Baumert, J., Richter, D., Voss, T., & Hachfeld, A. (2013). Professional competence of teachers: Effects on instructional quality and student development. *Journal of Educational Psychology*, 105(3), 805–820.
Kurnaz, M. A.,& Sağlam Arslan, A. (2011). A Thematic Review of Some Studies Investigating Students' Alternative Conceptions about Energy. *Eurasian Journal of Physics and Chemistry Education*, 3(1), 51-74.
Lam, R., & Muldner, K. (2017). Manipulating cognitive engagement in preparation-to-collaborate tasks and the effects on learning. *Learning and Instruction*, 52, 90-101. doi:10.1016/j.learninstruc.2017.05.002
Lee, S., & Branch, R. M. (2018). Students' beliefs about teaching and learning and their perceptions of student-centred learning environments. *Innovations in Education and Teaching International*, 55(5), 585–593.
Lee, E., Brown, M., Luft, J., & Roehrig, G. (2007). Assessing beginning secondary science teachers' PCK: Pilot year results. *School Science and Mathematics*, 107(2), 52–60.
Leedy, P.,& Ormrod, J. (2001). *Practical Research: Planning and Design* (7th ed.). Upper Saddle River, NJ: Merrill Prentice Hall. Thousand Oaks: SAGE Publications.
Leedy, P.D., & Ormorod, J.E. (2005). *Practical Research: Planning and Design*. Upper Saddle River: New Jersey.

Linacre, J.M. (2012).*A user's guide to winsteps® ministeps* (Version 3.74.0) Retrieved from http://www.winsteps.com
Lopez-Fernandez, O.,& Molina-Azorin, J. F. (2011). The use of mixed methods research in the field of behavioural sciences. *Quality & Quantity*, 45(6), 1459–1472. doi: 10.1007/s11135-011-9543-9
Loughran, J. J., Berry, A., & Mulhall, P. (2006). *Understanding and developing science teachers pedagogical content knowledge*. Rotterdam: Sense Publishers.
Loughran, J., Berry, A., & Mulhall, P. (2012). *Understanding and developing science teachers' pedagogical content knowledge* (2nd ed.). Rotterdam: Sense Publishers.
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.
Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining Pedagogical Content Knowledge*. Dordrecht: Kluwer.
Mahler, D., Großschedl, J., & Harms, U. (2017). Using doubly latent multilevel analysis to elucidate relationships between science teachers' professional knowledge and students' performance. *International Journal of Science Education*, 39(2), 213–237.
Mahomed, C. C., & Singh, P. (2011). Work-integrated learning skills: A comparison of teachers' perceptions about the PGCE with those of the student teachers in the Nelson Mandela Metropole, *Africa Education Review*, 8 (3), 504-528. DOI: 10.1080/18146627.2011.618700
Makgato, M., & Mji, A. (2006). Factors associated with high school learners' poor performance: a spotlight on mathematics and physical science, *South African Jourrnal of Education*, 26(2), 253-266.
Malcolm, S. A. (2018). The Impact of a Learning Study on the Practice of Experienced Physical Sciences Teachers Topic Specific PCK in Stoichiometry (Doctoral Thesis). University of the Witwatersrand, Johannesburg.
Malikow, M. (2006). Are teachers born or made? The necessity of teacher training programs. *Natural Forum od Teacher Education Journal*, 16(3), 1-3
Mansora, R., Lilia Halim, L., & Osman, K. (2010). Teachers' knowledge that promote students' conceptual understanding. *Social and Behavioral Sciences*, 9, 1835–1839.
Martin, M. O., Mullis, I. V. S., Foy, P., & Stanco, G. M. (2012). *TIMSS 2011 international results inscience*. Boston. Chestnut Hill, MA: TIMSS & PIRLS International Study Center, Boston College.
Mathewson, M., & Reid, J. (2017). (Re) turning to practice in teacher education: embodied knowledge in learning to teach. *Teachers and Teaching*, 23(1), 42–58.
Mavhunga, E. (2012). *Explicit inclusion of topic specific knowledge for teaching and the development of PCK in pre-service science teachers* (Doctoral Thesis). University of the Witwatersrand, Johannesburg South Africa.
Mavhunga, E. (2015b). The Nature of Interactions of the Components of Topic Specific Pedagogical Content Knowledge behave during pedagogical transformation of 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.
Mavhunga, E. (2018). Revealing the structural complexity of component interactions of topic-specific PCK when planning to teach. *Research in Science Education*, 1–22.
Mavhunga, E. (2019). Exposing Pathways for Developing Teacher Pedagogical Content Knowledge at the Topic Level in Science. In *Repositioning pedagogical content knowledge in teachers' knowledge for teaching science* (pp. 129–148). Singapore, Springer.
Mavhunga, E. (2020). Revealing the Structural Complexity of Component Interactions of Topic-Specific PCK when Planning to Teach. *Research in Science Education*, 50 (3), 965-986.
Mavhunga, E., Ibrahim, B., Qhobela, M., & Rollnick, M. (2016). Student teachers' competence to transfer strategies for developing PCK for electric circuits to another physical sciences topic. *African Journal of Research in Mathematics, Science and Technology Education*, 20(3), 299–313.
Mavhunga, E., & Rollnick, M. (2013). Improving PCK of chemical equilibrium in pre-service Teachers. *African Journal of Research in Mathematics, Science and Technology Education*, 17(1–2), 113–125.
Mavhunga, E., & Rollnick, M. (2017). Implementing PCK Topic by Topic in Methodology Courses. In A. Sickel, & S. Witzig (Eds.),*Designing and Teaching the Secondary Science Methods Course* (pp. 149–170). Rotterdam: Sense.
Mavhunga, E., & van der Merwe, D. (2020): Bridging Science Education's Theory–Practice Divide: A Perspective from Teacher Education Through Topic-Specific PCK. *African Journal of Research in Mathematics, Science and Technology Education*, DOI:10.1080/18117295.2020.1716496
Mazibe, E., Coetzee, C., & Gaigher, E. (2020). A comparison between reported and enacted pedagogical content knowledge (PCK) about graphs of motion. *Research in Science Education*, DOI: 10.1080/18117295.2020.1765607
McDonald, M., Kazemi, E., & Kavanagh, S. (2013). Core practices and teacher education pedagogies: A call for a common language and collective activity. *Journal of Teacher Education*, 64, 378–386.
McLaughlin, S. (2006). Rounding up students' conceptions on circular motion. *Iowa Science Teachers Journal*, 33(2), 7-15.
McMillan, H., & Schumacher, S. (2014). *Research in Education Evidence-Based Inquiry* (7th ed.). Edinburgh Gate Harlow: Pearson Education Limited.
McNicholl, J., Childs, A., & Burn, K. (2013) School subject departments as sites for science teachers 'learning pedagogical content knowledge. *Teacher Development*, 17 (2), 155-175, DOI: 10.1080/13664530.2012.753941
Merriam, S. B. (1995). What can you tell from An N of 1: Issues of validity and reliability in qualitative research? *PAACE Journal of Lifelong Learning*, 4, 51-60.
Merriam S. B. (1998), Qualitative research and case study applications in education, London: Sage.
Merriam, S. B. (2002). Introduction to Qualitative Research. San Fransisco, Jossey-Bass.
Merriam, S. B., & Tisdell, E. J. (2016). Qualitative Research: A Guide to Design and Implementation (4th ed.). United States of America: Jossey-Bass.

Miheso, J. (2018). *Examining the classroom teaching of beginning physical science teachers who graduated from a topic specific pedagogical content knowledge based undergraduate programme* (Doctoral thesis). University of the Witwatersrand, Johannesburg.

Mitchell, R., Charalambous, C. Y., & Hill, H. C. (2014). Examining the task and knowledge demands needed to teach with representations. *Journal of Mathematics Teacher Education*, 17, 37–60, DOI 10.1007/s10857-013-9253-4

Modisaotsile, B. M. (2012). The failing standard of basic education in South Africa, Africa. *Africa Institute of South Africa, Brief no. 72*. Available at http://www.ai.org.za/wp-cotent/uploads/dounloads/2012/03/No.-72.The-Failing-Standard-Of-Basic-Education-in-South-Africa1.pdf. Accessed 15 April 2017

Morrison, C., & Fitzpatrick, S. (1992). *Direct and indirect equating: A comparison of four methods using the Rasch model.Measurement and Evaluation Center*. The University of Texas at Austin. ERIC Document Reproduction Services No. ED 375152.

Mthethwa-Kunene, E., Onwu, G., & Villiers, R. (2015). Exploring biology teachers ' pedagogical content knowledge in the teaching of genetics in Swaziland science classrooms. *International Journal of Science Education,* 37(7), 1140–1165. https://doi.org/doi.org/10.1080/09500693.2015.1022624

Mukeredzi, T. G., Mthiyane, N., & Bertram, C. (2015). Becoming professionally qualified: The school-based mentoring experiences of part-time PGCE students. *South African Journal of Education,* 35, (2), 1-9.

Neumann, K., Kind, V., & Harms, U. (2019). Probing the amalgam: the relationship between science teachers' content, pedagogy and pedagogical content knowledge. *International Journal of Science Education,* 41(7), 847–861.

Niaz, M. (2001a). Response to contradiction: Conflict resolution strategies used by students in solving problems of chemical equilibrium. *Journal of Science Education and Technology*, 10, 205–211.

Nilsson, P. (2008). Teaching for understanding: The complex nature of pedagogical content knowledge in pre-service education. *International Journal of Science Education*, 30(10), 1281–1299.

Nilsson, P., & Karlsson, G. (2019). Capturing student teachers' pedagogical content knowledge (PCK) using CoRes and digital technology. *International Journal of Science Education,* 41(4), 419–447.

Nilsson, P., & Loughran, J. (2012). Exploring the development of pre-service science elementary teachers' pedagogical content knowledge. *Journal of Science Teacher Education*, 23(7), 699–721.

Nitz, S., Ainsworth, S. E., Nerdel, C., & Prechtl, H. (2014). Do student perceptions of teaching predict the development of representational competence and biological knowledge?. *Learning and instruction*, 31, doi:10.1016/J.learninstruc.2013.12.003.

Njie, B., & Asimiran, S. (2014). Case study as a choice in qualitative methodology, *Journal of Research and Method in Education,* 4(3), 35-40.

Noble, H., & Smith, J. (2015). Issues of validity and reliability in qualitative research. *Evidence Based Nursing*, 18 (2), 34-35.

Nowell, L. S., Norris, J. M., White, D. E., & Moules, N. J. (2017). Thematic Analysis: Striving to Meet the Trustworthiness Criteria. *International Journal of Qualitative Methods*, 16, 1–13.

Nyamupangedengu, E. (2016). Using Self-Study to Learn to Teach Genetics to Pre-Servive Teachers for Understanding and for Teaching. In: Buck G., Akerson V. (eds.). Enhancing Professional Knowledge of Pre-Service Teacher Education by Self-Study Research. ASTE Series in Science Education. Cham, Springer.

Ogunniyi, M. B., & Rollnick, M. (2015). Pre-service science teacher education in Africa: Prospects and challenges, *Journal of Science Teacher Education*, 26, 65-79.

Okanlawon, A.E. (2010). Constructing a framework for teaching reaction stoichiometry using pedagogical content knowledge. *Chemistry,* 19(2), 27-44.

Padilla, K., & Van Driel, J. (2011). The relationships between PCK components: the case of quantum chemistry professors. *Chemistry Education Research and Practice*, 12(3), 367–378.

Park, S., & Chen, Y. (2012). Mapping Out the Integration of the Components of Pedagogical Content Knowledge (PCK): Examples From High School Biology Classrooms. *Journal of Research inScience Teaching*, 49(7), 922–941. https://doi.org/10.1002/tea.21022

Park, S., Chen, Y., & Jang, J. (2008). Developing measures of teachers' pedagogical content knowledge for teaching high school biology. In *International conference of the Association for Science Teacher Education*. St. Louis, MI.

Park, S., Jang, J., Chen, Y., & 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., & Oliver, J. (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. https://doi.org/10.1007/s11165-007-9049-6

Park, S., & Suh, J. K. (2019). The PCK Map approach to capturing the complexity of enacted PCK (ePCK) and pedagogical reasoning in science teaching. In A. Hume, R. Cooper, & A. Borowski (Eds.),*Repositioning Pedagogical Content Knowledge in Teachers' Knowledge for Teaching Science* (pp. 185–197). Singapore, Springer.

Pearson, M. L., Albon, S. P., & Hubball, H. (2015). Case study ethodology: Flexibility, rigour and ethical considerations for the scholarship of teaching and learning. *The Canadian Journal for the Scholarship of Teaching and Learning,* 6 (3), 12.

Pelch, M. A., & McConnell, D. A (2016). Challenging instructors to change: A mixed methods investigation on the effects of material development on the pedagogical beliefs of geoscience instructors. *International Journal of STEM Education*, 3, 1–18.

Penn-Edwards, S. (2004). Visual Evidence in Qualitative Research: The Role of Videorecording.*The Qualitative Report*, 9(2), 266-277.

Ping, W. (2013). Introducing the Possible Advantages of the PGCE to STEPS: A Report on English Teacher Development in Rural Primary Schools in China. *International Forum of Teaching and Studies*, 9(2), 31-39.

Pitjeng, R., J. (2015). *Investigating the effect of an intervention on novice science teachers' topic specific pedagogical content knowledge.* (Doctoral thesis), University of the Witwatersrand, Johannesburg South Africa.

Pitjeng-Mosabala, P., & Rollnick, M. (2018). Exploring the development of novice unqualified graduate teachers' topic-specific PCK in teaching the particulate nature of matter in South Africa's classrooms. *International Journal of Science Education,* 40(7), 742–770.

Potter, C. S. (2012). Multimethod Research. In C. Wagner, B. Kawulich and M. Garner (Eds), *Doing Social Research: AGlobal Context*. London: McGraw-Hill.
Punch, K. (2009). Qualitative research design. In K. F. Punch (Ed.), Introduction to research methods in education. Newcastle Upon Tyne, UK: Sage.
M. Qhobela, M., & Moru, E. K. (2014). Understanding challenges physics teachers come across as they implement learner-centred approaches in Lesotho, *African Journal of Research in Mathematics, Science and Technology Education*, 18(1), 63–74.
Quilez-Pardo, J., & Solaz-Portolez, J. J. (1995). Students' and teachers' misapplication of Le Chatelier's principle: Implications for the teaching of chemical equilibrium. *Journal of Research in Science Teaching*, 32(9), 939-957
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).
Richardson, G., Byrne, L., & Liang, L. (2018). Making learning visible: Developing preservice teachers' pedagogical content knowledge and teaching efficacy beliefs in environmental education. *Applied Environmental Education & Communication*, 17(1), 41–56.
Rollnick, M. (2017). Learning about semi-conductors for teaching—The role played by content knowledge in pedagogical content knowledge (PCK) development. *Research in Science Education*, 47(4), 833–868.
Rollnick, M., Bennett, J., Rhemtula, M., Dharsey, N., & Ndlovu, T. (2008a). The place of subject matter knowledge in PCK – A case study of South African teachers teaching the amount of substance and equilibrium. *International Journal of Science Education, 30*(10), 1365-1387.
Rollnick., M., Davidowitz., B., & Potgieter., M. (2017). Is Topic Specific PCK Unique to teachers? In K. Hahl, Juuti, K, Lampiselka, J, Uitto, A & Lavonen, J. (Ed.), *Cognitive and Affective Aspects in Science Education Research* (pp. 69-85). Cham: Springer.
Rollnick, M., & Mavhunga, E. (2014). The relationship of PCK knowledge to practice: A case study of two pre-service teachers teaching chemical equilibrium. In *Conference of the Southern African Association for Research in Mathematics, Science and Technology Education*. Port Elizabeth, South Africa.
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). London: Routlege.
Rollnick, M., & Mavhunga, E. (2016). Can the Principles of Topic-Specific PCK be Applied across science topics? Teaching PCK in pre-service programme. In N. Papadouris, A.Hadjigeorgiou,C. Constantinou (Eds.),*Insights from Research in Science Teaching and Learning. Contributions from Science Education Research* (pp. 59-72). Cham, Springer.
Roness, D., & Smith, K. (2009). Postgraduate certificate in education (PGCE) and student motivation. *European Journal of Teacher Education*, 32 (2), 111-134, DOI: 10.1080/02619760902778982
Roth, K., Garnier, H., Chen, C., Lemmens, M., Schwille, K., & Wickler, N. (2011). Videobased lesson analysis: Effective science PD for teacher and student learning. *Journal of Research in Science Teaching*, 48(2), 117–148.
Rowley, J. (2002). Using case studies in Research, *Management Research News*, 25(1), 16-27
Sadler, P., Sonnert, G., Coyle, H., Cook-Smith, N., & Miller, J. (2013). The influence of teachers' knowledge on student learning in middle school physical science classrooms. *American Educational Research Journal*, 50(5), 1020–1049.

Schober, P., Boer, C., & Schwarte, L. A. (2018). Correlation coefficients: appropriate use and interpretation. *Anesthesiol Research and Practice*, 126 (5), 1763–1768.
Senocak, E. (2009). Development of an instrument for assessing undergraduate science students' perceptions: The problem-based learning environment inventory. *Journal of Science Education and Technology*, 18(6), 560–569.
Shenton, A.K. (2004). Strategies for ensuring trustworthiness in qualitative research projects. *Education for Information*, 22, 63-75.
Shulman, L. S. (1986). 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), 1–22.
Sibanda, D. (2018). What Sequence do we Follow in Teaching Concepts in Chemistry? A Study of High School Physical Science Teachers' PCK, *African Journal of Research in Mathematics, Science and Technology Education*, 22 (2), 196-208, DOI: 10.1080/18117295.2018.1484408
Smith, P. S., & Banilower, E. R. (2015). Assessing PCK: A new application of the uncertainty principle. In *Re-examining Pedagogical Content Knowledge in Science Education* (pp. 88–103). Oxford: Routledge.
Soudien, C., & Sayed, Y. (2003). Integrating South African Schools? Some Preliminary Findings. IDS Bulletin, 34 (1), 29-42.
Spaull, N. (2013). South Africa's education crisis: The quality of education in South Africa 1994-2011. Retrieved from doi.org/Report Commissioned by CDE
Strauss, S., Calero, C., & Sigman, M. (2014). Teaching, naturally. Trends in Neuroscience and Education, 3, 38-43
Strauss, S., & Ziv, M. (2012). Teaching is a natural cognitive ability for humans. *Mind Brain Education*, 6(4), 186-196
Strauss, S., Ziv, M.,& Stein, A. (2002). Teaching as a natural cognition and its relations to preschoolers' developing theory of mimd. Cognitive Development, 17, 1473-1487
Stutchbury, K. (2014). In pursuit of quality: the challenges and opportunities for teacher education. In *AFTRA, 2014,* Accra, Ghana.
Talanquer, V. (2011). Macro, Submicro, and Symbolic: The many faces of the chemistry "triplet". *International Journal of Science Education*, 33(2), 179–195. https://doi.org/10.1080/09500690903386435
Tan, F., Whipp, P., Gagné, M., & Van-Quaquebeke, N. (2019). Students' perception of teachers' two-way feedback interactions that impact learning. *Social Psychology of Education*, 22(1), 169–187.
Taylor, N. (2014). *Initial Teacher Education research:An examination of aspects of initial teacher education curricular at five higher education institutions*. Johannesburg: JET Education Services.
Teddlie, C., & Tashakkori, A. (2009). *Foundations of mixed methods research: Integrating quantitative and qualitative approaches in the social and behavioural sciences*. Thousand Oaks, CA: Sage.
Thomas, P. L., & Schwarz, R. W. (1998). College physical chemistry students' conceptions of equilibrium and fundamental thermodynamics. *Journal of Research in Science Teaching*, 35, 1151–1160.

Tobin, K., & McRobbie, C. (1999). Pedagogical content knowledge and co-participation in science classrooms. In J. Gess- Newsome & N.G. Lederman (Eds.), *Examining PedagogicalCcontent Knowledge* (pp. 215-234). Dordrecht, The Netherlands: Kluwer.

Toerien, R. (2017). *Mapping the learning trajectories of physical sciences teachers' topic specific knowledge for teaching chemical bonding*(Doctoral thesis). University of Cape Town, Cape Town, South Africa

Tondeur, J., Van Braak, J., Sang, G., Voogt, J., Fisser, P., & Ottenbreit-Leftwich, A. (2012). Preparing pre-service teachers to integrate technology in education: A synthesis of qualitative evidence. *Computers & Education*, *59*(1), 134–144.

Tyson, L., & Treagust, D.F., Bucat, R.B. (1999). The Complexity of Teaching and Learning Chemical Equilibrium. *Journal of Chemical Education*, 76(4), 554-557.

Undiyaundeye, F. (2015). The Born and the Made Teacher: Harmonizing the Gains of Both for Teaching Efficiency. *International Journal of Interdisciplinary Research and Innovations*, 3(1), 20-24.

van Driel, J. H., Berry, A., & Meirink, J. (2014). Research on Science Teacher Knowledge. In Handbook of Research on Science Education (pp. 848–870). New York: Taylor and Francis.

van Driel, J. H., & Graber, W. (2002). The Teaching and learning of Chemical Equilibrium. In J. K. Gilbert, O. D. Jong, R. Justi, D. F. Treagust & J. H. Van Driel (Eds.*),Chemical Education:Towards Research-based Practice* (pp. 271-292). London: Kluwer Academic Publisher.

van Driel, J. H., & Henze, I. (2012). Extended paper for PCK Summit, Colorado 2012. Retrieved from http:// pcksummit.bscs.org

van Driel, J. H., Verloop, N., & Vos, W. De. (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.

Venkatesh, V., Brown, S. A., & Bala, H. (2013). Bridging the qualitative-quantitative divide: guidelines for conducting mixed methods research in information systems. MIS Q., 37(1), 21-54

Wagner, C., Kawulich, B., & Garner, M. (2012). Doing Social Research. *A global context*,McGraw Hill.

Wheeler, A. E., & Kass, H. (1978). Student misconceptions in chemical equilibrium. *Science Education in Chemistry*, 62, 223-232.

Whitley, E., & Ball, J. (2002). Statistics review 6: Nonparametric methods. Critical Care, 6(6), 1–5.

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.

Windschitl, M., Thompson, J., Braaten, M., & Stroupe, D. (2012). Proposing a core set of instructional practices and tools for teachers of science. *Science Education*, 96, 878–903.

Witzig, S. B., & Sickel, A. J. (2017). Setting the landscape. Focusing on the methods course in secondary science teacher education: *In A.J. Sickel & S.B. Witzig (Eds.)., Designing and teaching the secondary science methods course*: an international perspective (pp. 1–8). Rotterdam: Sense Publishers.

Wright, B. D. (1996). Reliability and Separation. *Rasch Measurement Transactions*, 9, 472. Retrieved 11 October 2012 from www.rasch.org/rmt/rmt94n.htm
Yin, R. K. (2003). *Case Study Research: Design and Methods* (3rd.ed.). London: Sage Publications
Yin, R. K. (2012a). Applications of Case Study Research (3rd ed.). Thousand Oaks, CA: Sage.
Yip, J., Wong, S., Yick, K., Chan, K., & Wong, K. (2019). Improving quality of teaching and learning in classes by using augmented reality video. *Computers & Education*, 128, 88–101.

Appendix A: TSPCK tool in Chemical Equilibrium

CHEMICAL EQUILIBRIUM TSPCK

The information will be used for research purposes only: your responses will be treated confidentially. Codes will be used to protect your identity.

NAME AND SURNAME: _____Gender (tick ✓): | Female | Male |

NAME OF HIGHEST QUALIFICATION IN SCIENCE: _____

MAJOR SUBJECTS: _____

NAME OF HIGHER EDUCATION INSTITUTION WHERE HIGHEST QUALIFICATION IN SCIENCE WAS RECEIVED:
_____PROVINCE: _____

Kindly describe your activities in the last 3 years (e.g., studying, working, study break, etc.). Please provide as many details as possible:
_____
_____

CATEGORY A:

1. In a classroom setting, which of the following responses will you choose to answer a learner who seems to be in doubt and asks you:

   "Do both the forward and the backward reaction actually take place if a closed system is at equilibrium?"

   Response A: Yes; the rate at which the forward reaction occurs is the same as the rate at which the backward reaction occurs. We do not see them because both reactions happen under a microscopic eye.

   Response B: Yes; for a reaction to be considered as at equilibrium, the rate of the forward reaction is the same as the rate of the reverse reaction. As products are formed, they decompose or react with each other and form reactants. In this way the reaction is kept at equilibrium.

   Response C: Yes; a reaction that is at equilibrium has a forward and a reverse reaction. The forward reaction produces products, and the backward reaction produces reactants. Sometimes the concentration of products is higher than the reactants, sometimes vice versa.

   Response D: None of the above.

Choose your response and use the space below to expand on your choice.

My choice is Response ….

2. What comment would you write on a learner's script who writes:

A reaction reaches equilibrium when the concentrations of the products and reactants are equal.

Response A: No; when a reaction reaches equilibrium, it does not mean the concentrations of the reactants and products are equal. The concentration of reactants and those of products are not equal at equilibrium. Sometimes the concentration of reactants is more than that of products and vice-versa. It depends on the type of reaction.

Response B: No*;* when a reaction reaches equilibrium the concentration of the products and the reactants are not equal. Equilibrium is reached when both reactions proceed at the same rate.

Response C: No; the concentration of reactants and products at equilibrium are not equal. Each reagent may have its own concentration which is different from the other. What ensures a reaction to be at equilibrium is the rate at which the forward and the reverse reaction occur. For equilibrium to occur this rate must be equal for both reactions.

Response D: None of the above

Choose your response and use the space below to expand on your choice.

My choice is Response….

CATEGORY B:

Questions 3.1 -3.4 relate to planning and sequencing of concepts.

3.1 What do you consider to be the **three main ideas** (main concepts) to be taught about equilibrium at Grade 12? Choose from the list provided.

Dynamic equilibrium	Equilibrium constant
Chemical reactions	Rate of reaction
Lê Chatelier's principle	Equilibrium shift
Factors that affect equilibrium	Calculation of equilibrium concentrations
Open and closed systems	Homogeneous and Heterogeneous equilibrium
Physical equilibrium	Forward reaction and reverse reaction
Extent of reaction	Other

4.
5.
6.

3.2 Make a map or a diagram of these three ideas showing how they link to the subordinate ideas.

6.3 What topics must have been covered in chemistry before you can teach chemical equilibrium?

List of Topics to be taught before Chemical Equilibrium	**Place them in a sequence** (the one to be taught first, place it as No. 1)	**Provide reasons for the proposed sequence**
	1.	
	2.	
	3.	
	4.	

3.4 Why is it important for learners to learn about equilibrium? Identify reasons related to:

v. Sequencing
vi. Application
vii. Motivation or Interest

CATEGORY C:

4. Tick (✓), from the list below, the concepts of chemical equilibrium that you consider difficult to teach. You may also add your own. Explain why you consider the chosen topics difficult to teach.

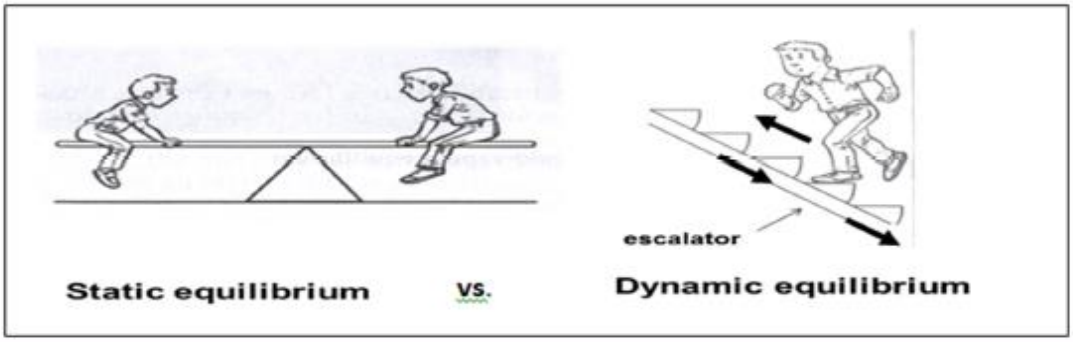
Concept	✓	Why considered difficult?
Closed and open system		
The calculation of concentration using the (RICE) **r**atio/ **I**nitial/**C**oncentration/**E**quilibriu m Table		
Physical equilibrium vs. chemical equilibrium		
Calculations of concentrations vs. calculations of moles		
Working with the equilibrium constant in calculations, just a number with no units		
Using mathematical ratios in a chemical concept		
Dynamic equilibrium – in chemical systems		

CATEGORY D:

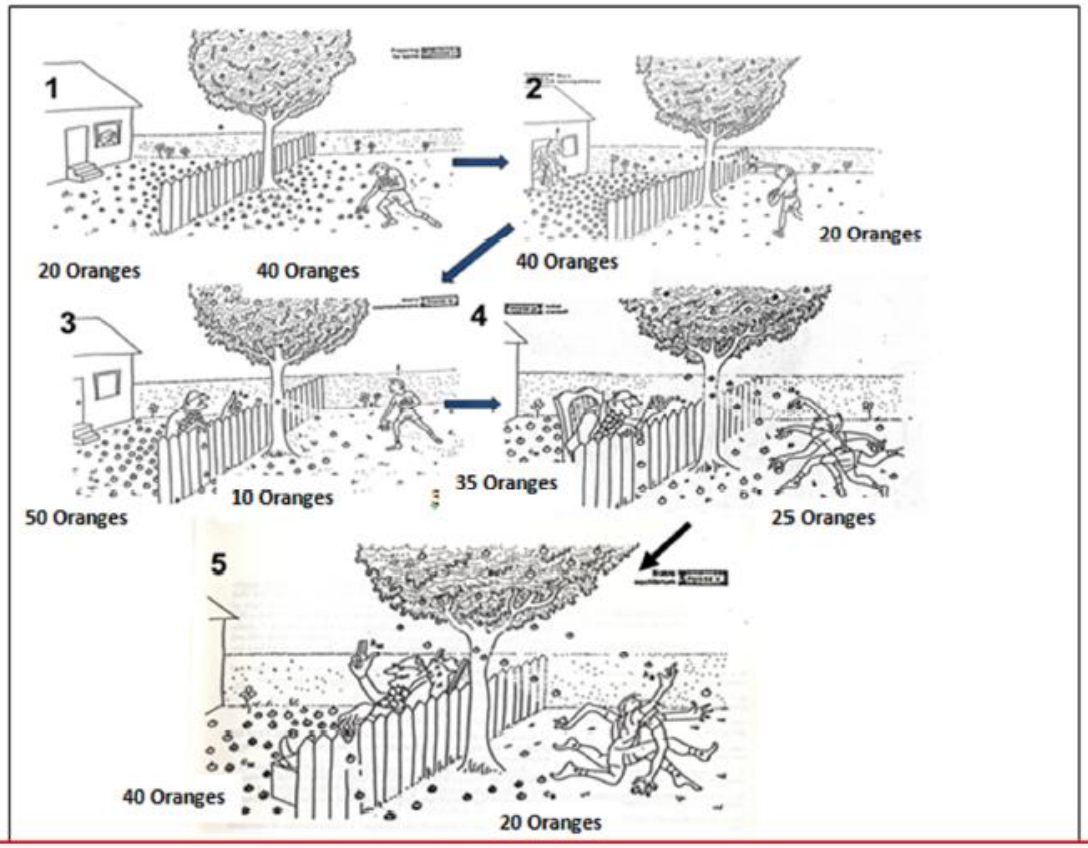
Dynamic and Static equilibrium

5. Below are possible representations/analogies/models for teaching the concept of static versus dynamic equilibrium.

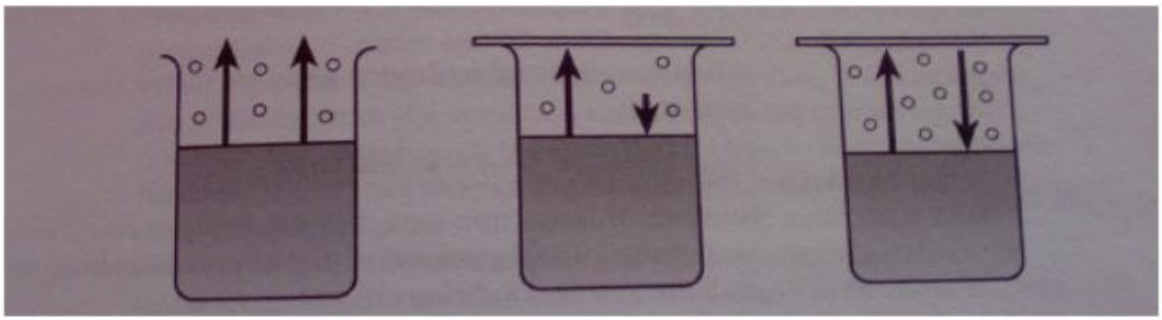
Representation 1



Representation 2



Representation 3



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

Representation No.	What I Like	What I do not like
1		
2		
3		

5.2 Which representation do you like most?

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

CATEGORY D:

Le Châtelier's' Principle

6. Following below is a student's written response in a class test designed to assess prior knowledge of students about Le Châtelier's' Principle.

Question:

What is the effect of adding more water to the reaction given below at equilibrium?

$$CH_3CO_2H(aq) + H_2O\ (l) \rightleftharpoons CH_3CO_2^-\ (aq) + H_3O^+(aq)$$

A student responded:

'More $CH_3CO_2^-$ (aq) and H_3O^+ (aq) will be formed, to counteract the effect of adding more water to the reactants. This will happen until a new equilibrium is reached'.

6.1 Following the student's response, how will you teach a lesson on predicting the effect of the factors disturbing the equilibrium?

Appendix B: Content Representation (CoRe)

Components of Topic Specific PCK		Big Idea 1	Big Idea 2	Big Idea 3
All these questions including formulation of Big Ideas are considered to be elements of the component of TSPCK called curricular saliency	What would you consider as Big Ideas for this topic?			
	What do you intend the learners to know about this idea?			
	Why is it important for the learners to know this Big idea?			
	What concepts need to be taught before teaching this Big idea?			
	What else do you know about this idea (that you do not intend the learners to know yet)?			
What is difficult to understand	What do you consider easy or difficult in teaching this Big idea? Provide the reasons.			
Learner Prior Knowledge	What are the typical student misconceptions in this Big idea?			
	How would you go about correcting them?			
Representations	What representations would you use in your teaching strategies, and why?			
Conceptual teaching strategies	What conceptual teaching strategies would you use in teaching this Big idea?			

Appendix C: An interview protocol

Post-lesson interview questions

1. How do you think the intended lessons objectives were achieved?
2. Could you recall what assisted you to explain the concepts?
3. What challenges did you experience?
4. What (if any) would you do differently next time?

Stimulated Recall Interview

Show each PPST several video clips on their teaching of the lesson (s) on the topic. The aim is to recap their memories on various lesson episodes. This is followed by some questions related to each video episode after viewing the video together.

1. What concept(s) related to the topic did you want to bring out from this teaching and learning activity?
2. Was this instructional activity planned? How did you come up with that idea?
3. In what way is this strategy useful in helping the students to learn the concept(s) that you want them to understand?
4. Have you thought of any other ways to explain this key concept? If so, why didn't you choose the alternative ways?
5. When the learner said this /asked this question you responded by saying (repeat what teacher said) and your response was (repeat what teacher said). What were the reasons for giving this response? Why?
6. You used (an animation, picture and analogy) to help students learn…. Why? Are there any particular reasons for the use of this (strategy) for teaching?
7. Overall, do you think this activity worked well in achieving its planned objective (s)? Are you satisfied with the activity? Why?
8. Will you use the same activity in your next round of teaching? Why or why not? If yes, how would you modify this activity in your next round of teaching?

Appendix D: Achievement test on Chemical Equilibrium (with marking memo)



Division of Science and Technology Education

LEARNER ACHIEVEMENT TEST

TOPIC: Chemical Equilibrium

Instructions:

This achievement test is for research purposes only. Your responses will be kept confidential.

Name: ……

1. At equilibrium, _____.

A. The rates of the forward and reverse reactions are equal

B. The rate constants of the forward and reverse reactions are equal

C. All chemical reactions have ceased

D. The value of the equilibrium constant is 1

2. The reaction represented below reaches equilibrium in a closed container:

$CuO_{(s)} + H_{2(g)} \rightleftharpoons Cu_{(s)} + H_2O_{(g)}$ $\Delta H < 0$

Which ONE of the following changes will increase the yield of products?

A. Increase temperature.

B. Decrease temperature.

C. Increase pressure by decreasing the volume.

D. Decrease pressure by increasing the volume.

3. Which of the following is true regarding the concentration of products, for a chemical reaction that is already at equilibrium, assuming no disruptions to the equilibrium?

A. The concentrations of products will not change because there are no more reactants.

B. The concentrations of products will not change because the limiting reagent is gone.

C. The concentrations of products will not change because the forward and reverse rates are equal.

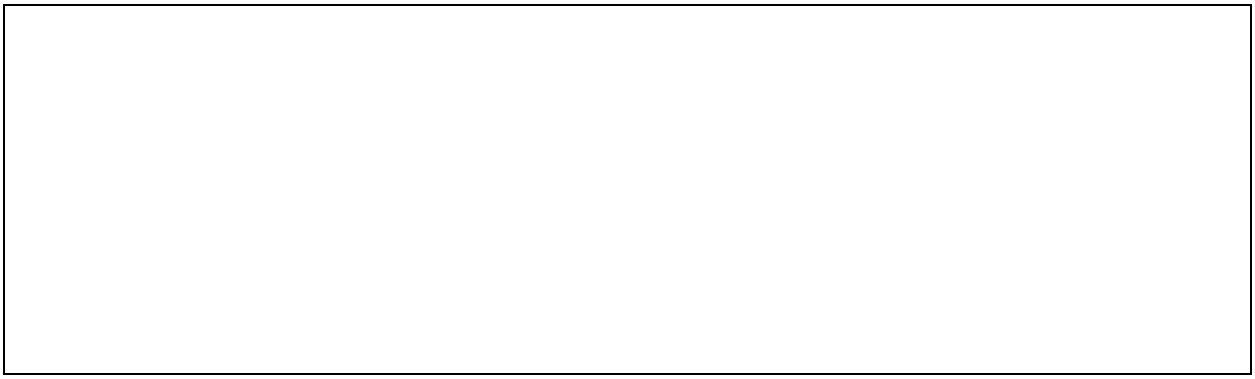
D. The concentrations of products will change continually because of reversibility.

4. What happens to a chemical reaction that has reached an equilibrium state when a disturbance is added?

……
……
……
……

5. The reaction below represents the decomposition of $N_2O_{4(g)}$ in a closed container according to the following equation: $N_2O_{4(g)} \rightleftharpoons 2NO_{2(g)}$

On the space provided, draw a concentration vs time graph for this reaction at equilibrium



6. Explain what is meant by the following:

a) Open system:

……
……

b) closed systems:

……
……

c) reversible reaction:

……
……

d)Dynamic equilibrium:

……
……

7. An unknown gas, $X_{2(g)}$, is sealed in a container and allowed to form $X_{3(g)}$ at 300 °C. The reaction reaches equilibrium according to the following balanced equation: $3X_{2(g)} \rightleftharpoons 2X_{3(g)}$

a) How will the rate of formation of $X_{3(g)}$ compare to the rate of formation of $X_{2(g)}$ at equilibrium? Write down only HIGHER THAN, LOWER THAN or EQUAL TO.
   ……..
b) More $X_{3(g)}$ is now added to the container. How will this change affect the amount of $X_{2(g)}$? Write down INCREASES, DECREASES or REMAINS THE SAME.
   ……
c) Use the Le Chatelier's principle to explain the answer to QUESTION 8b.
   ……
   ……

LEARNER ACHIEVEMENT TEST

TOPIC: Chemical Equilibrium

Instructions:
This achievement test is for research purposes only. Your responses will be kept confidential.

Name: KEAM

PRE- TEST RESPONSE

1. At equilibrium, _____.

(A) The rates of the forward and reverse reactions are equal

B The rate constants of the forward and reverse reactions are equal

C All chemical reactions have ceased ✓ 1

D The value of the equilibrium constant is 1

2/12

2. The reaction represented below reaches equilibrium in a closed container:

$CuO(s) + H_2(g \rightleftharpoons Cu(s) + H_2O(g) \quad \Delta H < 0$ endothermic

Which ONE of the following changes will increase the yield of products?

A Increase temperature.

B Decrease temperature. a

C Increase pressure by decreasing the volume.

(D) Decrease pressure by increasing the volume.

3. Which of the following is true regarding the concentration of products, for a chemical reaction that is already at equilibrium, assuming no disruptions to the equilibrium? ✓ 1

A The concentrations of products will not change because there are no more reactants.

B The concentrations of products will not change because the limiting reagent is gone.

(C) The concentrations of products will not change because the forward and reverse rates are equal.

D The concentrations of products will change continually because of reversibility.

4. What happens to a chemical reaction that has reached an equilibrium state when a disturbance is added?

The chemical reaction will either favour the reverse reaction or the forward reaction, based on what the disturbance is – if temperature is increased and the forward reaction is endothermic, the reverse reaction will be favoured.

5. The reaction below represents the decomposition of $N_2O_4(g)$ in a closed container according to the following equation: $N_2O_4(g) \rightleftharpoons 2NO_2(g)$

On the space provided, draw a concentration vs time graph for this reaction at equilibrium



6. Explain what is meant by the following:

a) Open system:

A system whereby the reactants and the products react with the surroundings

b) closed systems:

A system whereby the reactants and the products react with each other

c) reversible reaction:

A reaction that remains the same, whether the products are reacted together - they will produce the exact same reactants that were used to form them

d)Dynamic equilibrium:

7. An unknown gas, $X_2(g)$, is sealed in a container and allowed to form $X_3(g)$ at 300 °C. The reaction reaches equilibrium according to the following balanced equation: $3X_2(g) \rightleftharpoons 2X_3(g)$

a) How will the rate of formation of $X_3(g)$ compare to the rate of formation of $X_2(g)$ at equilibrium? Write down only HIGHER THAN, LOWER THAN or EQUAL TO.

HIGHER THAN 4

b) More $X_3(g)$ is now added to the container. How will this change affect the amount of $X_2(g)$? Write down INCREASES, DECREASES or REMAINS THE SAME.

~~INCREASE~~ DECREASES 4

c) Use Le Chatelier's principle to explain the answer to QUESTION 8b.

When the amount of $X_{3(g)}$ is added to the system, a disturbance occurs. The forward reaction will then be favoured and the amount of $X_{2(g)}$ will then decrease 9

POST-TEST RESPONSE

1. At equilibrium, _____.

A The rates of the forward and reverse reactions are equal

B The rate constants of the forward and reverse reactions are equal

C All chemical reactions have ceased

D The value of the equilibrium constant is 1

2. The reaction represented below reaches equilibrium in a closed container:

$CuO(s) + H_2(g \rightleftharpoons Cu(s) + H_2O(g) \quad \Delta H < 0$

Which ONE of the following changes will increase the yield of products?

A Increase temperature.

B Decrease temperature.

C Increase pressure by decreasing the volume.

D Decrease pressure by increasing the volume.

3. Which of the following is true regarding the concentration of products, for a chemical reaction that is already at equilibrium, assuming no disruptions to the equilibrium?

A The concentrations of products will not change because there are no more reactants.

B The concentrations of products will not change because the limiting reagent is gone.

C The concentrations of products will not change because the forward and reverse rates are equal.

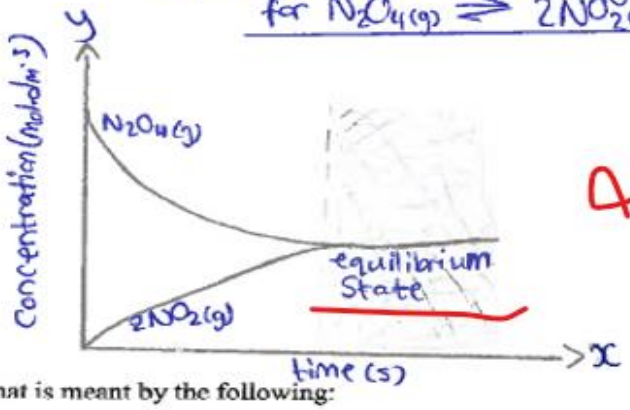
4. What happens to a chemical reaction that has reached an equilibrium state when a disturbance is added?

The disturbance will cause stress to the system; therefore the system will act in such a way to oppose the disturbance that has occured so that equilibrium can be established again ✓ 1

5. The reaction below represents the decomposition of $N_2O_4(g)$ in a closed container according to the following equation: $N_2O_4(g) \rightleftharpoons 2NO_2(g)$

On the space provided, draw a concentration vs time graph for this reaction at equilibrium

Concentration vs time graph for $N_2O_{4(g)} \rightleftharpoons 2NO_{2(g)}$



4

6. Explain what is meant by the following:

a) Open system:

matter and energy can escape or enter into the system ✓ 1

b) closed systems:

matter and energy cannot escape or ✓

c) reversible reaction:

a reaction whereby the reactants react continuously to form the products and the products continuously break down to form the reactants ✓ 1

d)Dynamic equilibrium:

a state ~~whereby~~ in a closed system whereby the forward and reverse reaction rates are the same with the pressure, the temperature and concentration of the reactants and products ~~are~~ remain constant at equilibrium ✓ 1

7. An unknown gas, $X_2(g)$, is sealed in a container and allowed to form $X_3(g)$ at 300 °C. The reaction reaches equilibrium according to the following balanced equation: $3X_2(g) \rightleftharpoons 2X_3(g)$

a) How will the rate of formation of $X_3(g)$ compare to the rate of formation of $X_2(g)$ at equilibrium? Write down only HIGHER THAN, LOWER THAN or EQUAL TO.

EQUAL TO ✓ 1

b) More $X_3(g)$ is now added to the container. How will this change affect the amount of $X_2(g)$? Write down INCREASES, DECREASES or REMAINS THE SAME.

INCREASE ✓ 1

c) Use Le Chatelier's principle to explain the answer to QUESTION 8b.

When more $X_{3(g)}$ is added to the system, there is a disturbance. The reverse reaction will be favoured therefore ~~the~~ $X_{2(g)}$ will also increase and the overall system will in turn also increase. ?

Appendix E: Questions for collecting the learners' views about the pre-service teachers







LEARNERS' VIEWS ABOUT UNIVERSITY STUDENT-TEACHERS' TOPIC SPECIFIC PCK

NAME:

Information:

The questions below are for research purposes only. Your responses will be kept confidential. Your responses will help us to improve the quality of physical sciences teaching and learning.

1. What did the student-teacher do, that helped you to understand the concepts? Give an example.
2. What was done in the class by the student-teacher that you liked most?
3. What was done in the class by the student-teacher that you did not like?
4. What do you think would help you to understand better?

Appendix F: A rubric for measuring planned TSPCK

	Limited(1)	(2) Basic	(3) Developing	Exemplary (4)
Learner Prior Knowledge	• No identification/No acknowledgement/No consideration of student prior knowledge or misconceptions • Repeats standard definition with reference to any other component of TSPCK	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Repeats standard definition drawing on one other component of TSPCK	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Expands and re-phrase explanation using two other component of TSPCK interactively	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Expands and re-phrases explanation correctly • Confronts misconceptions/confirms accurate understanding drawing on three or more other component of TSPCK interactively
Curriculum Saliency	• Identified concepts are a mix of Big Ideas and most important subordinate ideas • Identified subordinate ideas are a mix with those of other topics or no subordinates provided • Identified pre-concepts are a mix with those to be taught in current topic • Sequencing no value due to mixed concepts • Reasons given for importance of topic limited to generic benefit of education	• Identifies at least 3 Big Ideas • Not all 3 Big ideas have most important subordinate concepts identified however those identified are correct • Suggested sequencing has one or two illogical placing of main concepts (Big Ideas) • Identified pre-concepts are far from the current topic, they refer to concepts basic to the subject. • Reasons given for importance of topic exclude conceptual considerations such as scaffolding or sequential development for other topics in the subject.	• Identifies at least 3 Big Ideas • Identified most important subordinate ideas and shows (symbolic) links to Big ideas with no additional explanations • Provides logical sequence of concepts of all three Big Ideas. • Identifies pre-concepts includes those needed for the current topic • Reasons given for importance of topic include reference to conceptual scaffolding/sequential development of understanding of other topics in the subject however without specifying the topics • Reasons may also draw interactively on what makes topic difficult	• Identifies at least 3 Big Ideas • Identifies most important subordinate ideas and explains their links to the Big Ideas and to each other within a Big Idea • Provides logical sequence of all three Big Ideas and that of subordinate concepts within a Big idea • Identified pre-concepts include those needed specially in discussing the introductory definitions/aspects and those sequentially needed in the next Big Ideas of the current topic. • Reasons given for importance of topic include conceptual scaffolding/sequential development of understanding for specified subsequent topics in the subject.
What makes topic difficult	• Identifies broad topics without specifying the actual sub-concepts that are problematic • Reasons not given	• Identifies specific concepts but provides broad generic reasons such as 'abstract' • Reasons drawing on one other component of TSPCK	• Identifies specific concepts with reasons related to two other TSPCK	• Identifies specific concepts with reasons related to prior knowledge of specified students and aspects of curricular saliency • Provides reasons linking to specific gate keeping concepts that when not fully understood adds to the difficulty of a concept regarded as difficult – thus drawing on three or more TSPCK components
Representations	• Limited to use of only macroscopic analogies, demos, etc.) representation with no explanation of specific links to the concepts represented	• Use of macroscopic representation (analogies, demos, etc.) and use of scientific symbolic representation without explanatory notes to make the links to the aspects of the concept being explained.	• Use of macroscopic representation (analogies, demos, etc.) and use of scientific symbolic representation with explanatory notes linking the two representation to the aspect(s) of the concept being explained • Use of representation linked to two other TSPCK components e.g. learner prior knowledge and aspects of curricular saliency	• Use of macroscopic representation (analogies, demos, etc.) or symbolic representation and • Use of sub-microscopic representation to enforce a specific aspect (s) of the concept being explained • Explicit link/emphasis of core aspect of CK demonstrated in the representations. • Use of representation linked to other two components of TSPCK , likely to be learner prior knowledge and aspects of curricular saliency
Teaching Strategies	• No evidence of acknowledgement of student prior knowledge and misconceptions • Lacks aspects of curriculum saliency • Use of representations limited to macroscopic or symbolic scientific symbolic representation with no linking explanatory notes	• Acknowledges student misconceptions verbally with no corresponding confrontation strategy • Lacks aspects of curriculum saliency • Use of macroscopic and symbolic representations with no linking explanatory notes	• Considers confirmation/confrontation of student prior knowledge and/or misconceptions • Considers at least one aspect related to curriculum saliency: sequencing or what not to discuss yet or emphasis of important concepts • Uses at least two different levels of representations to enforce understanding and thus draws on other components of TSPCK in the process e.g. could be a curricular saliency aspect such as prior concept to be understood first and a clearly articulated understanding of potential difficulty that could result .	• Overall, excellent strategy to teach required concept • Considers student prior knowledge and evidence of confrontation of misconceptions. • Considers at least two aspects related to curriculum saliency: sequencing, what not to discuss yet, emphasis of important conceptual aspects, etc. • Uses either the macroscopic or symbolic representation with sub-microscopic representation to enforce understanding and uses three other components of TSPCK in the process e.g. could be a curricular saliency aspect such as prior concept to be understood first and a clearly articulated understanding of potential difficulty that could result perhaps because of what students know from another lesson that may appear to contradict current discussion

Appendix G: A rubric for measuring enacted TSPCK

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 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 TSPCK component interactions maybe interwoven or have a linear sequence structural formation or both • 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 interacting evidently and distinguishably in a specific teacher task segment Or • Evidence of four different TSPCK components interacting evidently and distinguishably in a specific teacher task segment, with one of the components repeated more than once or one of the components bringing different levels of sophistication (e.g. representations used at macro, symbolic and submicroscopic levels. • TSPCK component interactions maybe interwoven or have a linear sequence structural formation or both. • All the TSPCK components work together to support an explanation of a single or a pair of concepts that are related

Appendix H: Ethics Clearance report

Wits School of Education

WITS UNIVERSITY



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

27 November 2017

Student Number: 1304503

Protocol Number: 2017ECE039D

Dear Mamohato Violet Makhechane

Application for Ethics Clearance: Doctor of Philosophy

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

Exploring the mechanism through which the acquired competence to pedagogically transform content knowledge is transferred within planning and classroom contexts by PCGE student teachers

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

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

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

All the best with your research project.

Appendix I: GDE Approval



GAUTENG PROVINCE
Department: Education
REPUBLIC OF SOUTH AFRICA

8/4/4/1/2

GDE AMENDED RESEARCH APPROVAL LETTER

Date:	23 January 2018
Validity of Research Approval:	05 February 2018 – 28 September 2018 2017/254A
Name of Researcher:	Makhechane V.M
Address of Researcher:	Park Mews
	No. 1 Princess Place, Parktown
	Johannesburg 2193
Telephone Number:	060 773 2490
Email address:	1304503@students.wits.ac.za
Research Topic:	Exploring the mechanism through which the acquired competence to pedagogically transform content knowledge is transferred within planning and classroom contexts by PGCE student teachers
Number and type of schools:	Five Secondary Schools
District/s/HO	Johannesburg Central and Johannesburg East

Re: Approval in Respect of Request to Conduct Research

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

23/01/2018

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

1

Making education a societal priority

Office of the Director: Education Research and Knowledge Management
7th Floor, 17 Simmonds Street, Johannesburg, 2001
Tel: (011) 355 0488
Email: Faith.Tshabalala@gauteng.gov.za
Website: www.education.gpg.gov.za

Appendix J: Consent form to the Head of School

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

LETTER TO THE HEAD OF SCHOOL

DATE:

Dear Professor Karin Brodie,

My name is Mamohato Violet Makhechane, a PhD student in Science Education in the School of Education at the University of the Witwatersrand. I am doing research on the development of FET Physical science PGCE student teachers' Topic Specific Pedagogical Content Knowledge.

My research interest is on the physical science methodology class that the student teachers are taking. To develop the student teachers' professional knowledge, this course equips them with the teacher core competence referred to as Topic Specific Pedagogical Content Knowledge (TSPCK) in one selected chemistry topic, specifically topics that are in the high school syllabus. This competence, when acquired, helps to build the student teachers' pedagogical reasoning in the specific topic which can then be used to successfully transform the content knowledge of other topics into a teachable form so that the learners can comprehend it. The focus of this research study therefore is to explore these PGCE student teachers' pedagogical reasoning competence and development as a result of their exposure to the TSPCK construct of content knowledge transformation. To do so, the study will explore those student teachers' TSPCK in the context of planning to teach, its manifestation into classroom enactment, and how this influences learner performance. This involves following the student teachers in their second teaching experiences (TE).

The data will help the researcher to determine the effectiveness of the intervention in developing the student teachers' pedagogical reasoning competence so that their transformed content knowledge can be effectively accessed by the learners. The three lessons from each of the three volunteers PGCE student teachers will be audio/video-recorded during their TE after the intervention. The student teachers will be interviewed before and after the lesson observations and their lesson plans will be collected for further examination. I would also like to sit in their methodology class during the intervention in order to observe how the intervention is implemented, have access to all the work (including assignments and presentations if any) related to the intervention and use them as part of my research data. Only the work of those student teachers who have volunteered to participate in this research study will be included as my data.

Because participation is voluntary, any participant PGCE student teacher who may wish to withdraw from participating in this study will be free to do so and this will not in any way impact on their academic work. The participants will also be reassured of the confidentiality of all the data collected. Where all the video/audio recordings and transcriptions will be computer and USB

stored and protected with a password, while hard copy data such as lesson plans and assignments will be safely locked in my supervisor's office. All data will be made accessible only to me and my supervisor. On the analysis of the data, no real names of participants but pseudonyms will be used hence the participants will remain anonymous in all my written work. There are no foreseeable risks in participating in this study and the participants will not be paid for their participation.

Please let me know if you require any further information. I look forward to your response as soon as it is convenient.

Yours sincerely,

Name: Mamohato Violet Makhechane
Email: 1304503@students.wits.ac.za
Phone Number: 0607732490

Head of School's Consent Form

Please fill in to indicate your consent to allow your class to participate in the study.

Circle one

I agree that physical science methodology class should be used for this research study YES/NO

I agree that students' submitted work should be used for this research only YES/NO

I agree that the students should be followed into their TE and their records and lesson plans be used for this research study only YES/NO

Sign_____ Date_____

Appendix K: Consent form to the Course Coordinator

LETTER TO THE COURSE CO-ORDINATOR

DATE:

Dear Prof. Mavhunga,

My name is Mamohato Violet Makhechane, a PhD student in Science Education in the School of Education at the University of the Witwatersrand. I am doing research on the development of FET Physical science PGCE student teachers' Topic Specific Pedagogical Content Knowledge.

My research interest is on your physical science methodology class that the student teachers are taking which aims to develop the student teachers' professional knowledge by equipping them with teacher core competence referred to as Topic Specific Pedagogical Content Knowledge (TSPCK) in one selected chemistry topic, specifically topics that are in the high school syllabus, which when acquired helps in building the student teachers' pedagogical reasoning in that specific topic which can be used to successfully transform their content knowledge of other topics into a teachable form, so that the learners can comprehend. The focus of this research study therefore is to explore these PGCE student teachers' pedagogical reasoning competence and development as a result of their exposure to the TSPCK construct of content knowledge transformation. To do so, the study will explore those student teachers' TSPCK in the context of planning to teach, its manifestation into classroom enactment, and how this influences learner performance. This involves following the student teachers in their second teaching experiences (TE).

The second TE occurs after an exposure to the TSPCK construct and this will help the researcher to determine the effectiveness of the intervention in developing the student teachers' competence so that their transformed content knowledge can be effectively accessed by the learners. The three lessons of the three volunteer PGCE student teachers will be audio/video recorded during their TE. The student teachers will also be interviewed before and after the lesson observations which will be audio recorded and their lesson plans will be collected. I would also like to sit in their methodology class during the intervention in order to have the experience of how the intervention was implemented, and also access all their work (including assignments and presentations if any) related to the intervention and use them as part of the data for the study. Only the work of those student teachers who have volunteered to participate in this research study will be included as the data.

Because participation is voluntary, any participant PGCE student teacher who may wish to withdraw from participating in this study will be free to do so and this will not in any way have an impact on their academic work. The participants will also be reassured of the confidentiality of all the data collected. All the video/audio records and transcriptions will be computer and USB stored and protected with a password while hard copy data such as lesson plans and assignments will be safely locked in my supervisor's office. All data will be made accessible only to me and my supervisor. On analysis of the data, no real names of participants but pseudonyms will be used, hence the participants will remain anonymous in all my writings. There are no foreseeable risks in participating in this study and the participants will not be paid for this study.

Please let me know if you require any further information. I look forward to your response as soon as it is convenient.

Yours sincerely,

Name: Mamohato Violet Makhechane
Email: 1304503@students.wits.ac.za
Phone Number: 0607732490

Course Co-ordinator's Consent Form

Please fill in to indicate your consent to allow your class to participate in my study.

I, _____ give my consent for the following:

Circle one

I agree that physical science methodology class should be used for this research study YES/NO

I agree that students' submitted work should be used for this research only YES/NO

I agree that the students should be followed into their TE and their records and lesson plans be used for this research study only YES/NO

Sign_____ Date_____

Appendix L: Consent form to the Course Lecturer

LETTER TO THE COURSE LECTURER

DATE:

Dear Prof. Mavhunga,

My name is Mamohato Violet Makhechane, a PhD student in Science Education in the School of Education at the University of the Witwatersrand. I am doing research on the development of FET Physical science PGCE student teachers' Topic Specific Pedagogical Content Knowledge.

My research interest is on your physical science methodology class that the student teachers are taking which aims to develop the student teachers' professional knowledge by equipping them with teacher core competence referred to as Topic Specific Pedagogical Content Knowledge (TSPCK) in one selected chemistry topic, specifically topics that are in the high school syllabus, which when acquired helps to build the student teachers' pedagogical reasoning in that specific topic which can be used to successfully transform their content knowledge of other topics into a teachable form, so that learners can comprehend. The focus of this research study therefore is to explore these PGCE student teachers' pedagogical reasoning competence and development as a result of their exposure to the TSPCK construct of content knowledge transformation. To do so, the study will explore those student teachers TSPCK in the context of planning to teach, its manifestation into classroom enactment, and how this influences learner performance. This involves following the student teachers in their second teaching experiences (TE).

The second TE occurs after the exposure to the TSPCK construct and this will help determine the effectiveness of the intervention in developing further the student teachers' competence so that their transformed content knowledge can be effectively accessed by the learners. The study would audio/video record about four lessons of three volunteered PGCE student teachers during their TE, prior and post-intervention. The student teachers will also be interviewed before and after the lesson observations which will be audio recorded and their lesson plans collected. I would also like to sit in their methodology class during the intervention in order to have a view of how the intervention was implemented, and also access all their works (including assignments and presentations if any) related to the intervention and use them as part of the data. Only the work of those student teachers who have volunteered to participate in this research study will be included as the study data.

Because participation is voluntary, any participant PGCE student teacher who would wish to withdraw from participating in this study will be free to do so and this will not in any way impact their academic work. The participants will also be reassured of the confidentiality of all the data collected. All the video/audio records and transcriptions will be computer and USB stored and protected with a password, while hard copy data such as lesson plans and assignments will be safely locked in my supervisor's office. All the data will be made accessible only to me and my supervisor. On analyzing the data, no real names of participants but pseudonyms will be used hence the participants will remain anonymous in all my writings. There are no foreseeable risks in participating in this study and the participants will not be paid for this study.

Please let me know if you require any further information. I look forward to your response as soon as it is convenient.

Yours sincerely,

Name: Mamohato Violet Makhechane
Email: 1304503@students.wits.ac.za
Phone Number: 0607732490

Course Lecturer's Consent Form

Please fill in to indicate your consent to allow your class to participate in my study.

I, _____ give my consent for the following:

Circle one

I agree that physical science methodology class should be used for this research study YES/NO

I agree that students' submitted work should be used for this research only YES/NO

I agree that the students should be followed into their TE and their records and lesson plans be used for this research study only YES/NO

Sign_____ Date_____

Appendix M: Consent form to the PGCE pre-service teachers

LETTER TO THE PGCE STUDENT TEACHERS – PHYSICAL SCIENCE

DATE:

Dear PGCE student teacher,

My name is Mamohato Violet Makhechane, a PhD student in Science Education in the School of Education at the University of the Witwatersrand. I am doing research on the development of FET Physical science PGCE student teachers' Topic Specific Pedagogical Content Knowledge.

I am inviting you to participate in my research study. This study is aimed at improving a special teacher knowledge that assists teachers to efficiently teach specific topics, referred to as Topic Specific Pedagogical Content Knowledge (TSPCK). My research interest is on your physical science methodology class which aims to develop your professional knowledge by equipping you with core competence referred to as Topic Specific Pedagogical Content Knowledge (TSPCK) in one selected chemistry topic, specifically a topic that is on the high school syllabus, which when acquired helps in building your pedagogical reasoning in that specific topic which can be used to successfully transform your content knowledge of other topics into a teachable form, such that learners can comprehend. The focus of this research study therefore is to explore your pedagogical reasoning ability and development as a result of an exposure to the TSPCK construct of content knowledge transformation. To do so, the study will explore the TSPCK components that occur naturally in your teaching before the intervention, versus those that are seen in classroom practice after treatment.

I would also like to sit in the methodology class during the intervention in order to observe how the intervention is implemented and also to access all your submitted work (including assignments and presentations if any) related to the intervention and use them as part of the study data. I will also follow some of you (3 who will volunteer) during second teaching experiences (TE). The second TE occurs after the exposure to the TSPCK construct and this will help determine the effectiveness of the intervention in developing further your pedagogical reasoning competence so that your transformed content knowledge can be effectively accessed by the learners. Four lessons of each of the three volunteer PGCE student teachers will be audio/video recorded during the TE. The student teachers will also be interviewed before and after the lesson observations which will be audio recorded and their lesson plans collected. Only the work of those student teachers who have volunteered to participate in this research study will be included as the study data.

Because participation is voluntary, any participant who wishes to withdraw from participating in this study will be free to do so without fear of prejudice and this will not in any way have an impact on your academic work. Confidentiality of all the collected data will be maintained at all times, where all the video/audio records and transcriptions will be computer and USB stored and protected with a password. The hard copy data such as lesson plans and assignments will be safely locked in my supervisor's office. All the data will be accessible only to me and to my supervisor. On the analysis of the data, the real names of participants will not be used; only the pseudonyms will be used, hence the participants will remain anonymous in all my written work and the data will be destroyed between 3-5 years after I have completed my project. There are no foreseeable

risks in participating in this study and the participants will not be paid for participating in this study.

If you wish to have further information regarding your rights, as a research participant, you may contact: Human Research Ethics Committee (HREC) at 0117173055 or Ms. Matsie Mabeta via email at
Matsie.Mabeta@wits.ac.za.

I look forward to working with you!

Please feel free to contact me if you have any questions.

Thank you

Name: Mamohato Violet Makhechane
Email: 1304503@students.wits.ac.za
Phone Number: 0607732490

PGCE STUDENT TEACHER'S CONSENT FORM

Please fill in below indicating your willingness voluntarily participate in my study

I, _____ give my consent for the following:

Circle one

I agree to participate in this research study and to have my submitted work used for this study: YES/NO

I agree to be followed into TE and agree that all the information gathered may be used only for this research study: YES/NO

I agree that my lessons maybe video/audio recorded and that all the recordings maybe used for this research study only: VIDEO/AUDIO

I agree to be interviewed and to have the information gathered used for this research study only: YES/NO

Informed Consent
I understand that:

- my name and information will be kept confidential and safe and that my name and the name of my school will not be revealed.

- I am not forced to respond to the questions that I am not comfortable with and can withdraw from the study at any time.
- I can ask not to be video/audio recorded.
- All the data collected during this study will be destroyed within 3-5 years after completion of my project.

Sign_____ Date_____

Appendix N: Consent form to the Principals

LETTER TO THE SCHOOL PRINCIPAL

DATE:

Dear Principal,

My name is Mamohato Violet Makhechane, a PhD student in Science Education in the School of Education at the University of the Witwatersrand. I am conducting research on the development of (senior phase/FET) PGCE student teachers' Pedagogical reasoning ability for specific science topics. The research aims at improving special teacher knowledge for teaching science topics efficiently. The knowledge is called Topic Specific Pedagogical Content Knowledge (TSPCK). The approach of TSPCK is considered valuable by the science education community, nationally and internationally in improving teacher effectiveness in teaching for understanding.

The research is at a stage where I need to evaluate the effectiveness of teaching by our student teacher posted to your school for a teaching experience this academic session. I would like to use this opportunity to evaluate the quality of his/her teaching. In order to do this, at least one of the student teacher's lessons will be video/audio recorded to capture their TSPCK in action. I will stand behind the learners in the class to video/audio record the moves and actions of the student teacher and the learners during the lesson. This will allow the research do explore through this observations and records, the ability of the teacher to transform content for accessibility by the learners. I will also need to interview the student teacher prior to and post every lesson observation.

I therefore need your permission to carry the above laid activities. I am aware that consent is also needed from not only the supervising teacher but also from the learners' parents and from learners as learners are likely appear in the video records and their voices captured through audio records. Such consent forms have been prepared and their samples attached to this letter. I have also attached to this letter, approvals from GDE and from Wits University Ethics committee. The learners' responses that will be captured through the records during the lesson observations will not be made public, but they will be accessible only to me and my supervisor. Efforts will be made to avoid capturing of learners who have not consented and if captured unavoidably, their faces will be screen blocked. The recordings will be kept confidential and saved under password. The learners' names, school's name and the identities will be kept confidential at all times in all my academic written work. The privacy of the learners will be maintained in all published and written data resulting from this study. If a need arises that we need to quote from the recordings and a learner's name was mentioned by the student teacher, a pseudo name will be assigned to the person quoted.

Your learners will not be advantaged or disadvantaged in any way. They will be reassured that they can withdraw their permission to be video recorded at any time during this research without any penalty. There are no foreseeable risks in participating in this study. Your learners will not be paid for participating in this study.

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

Thank you for your help.

Yours sincerely,

Name: Mamohato Violet Makhechane

Address: Wits University, Education Campus, Science and Education Technology Division, 27 St. Andrew Road, Parktown.

Email: 1304503@students.wits.ac.za

Phone Number: 0607732490

SCHOOL PRINCIPAL'S CONSENT FORM

Please fill in the blanks below as an indication of your approval, allowing your school and the learners to participate in my voluntary research project called Topic Specific Pedagogical Content Knowledge.

I, _____ give my consent for the following:

Please Circle one

I agree that my school should participate in this research study and that all the recordings be used only for this research. YES/NO

I agree that the learners taught by the Wits PGCE student teachers can be audio recorded and the captured responses maybe used only for this study. YES/NO

I agree that the learners taught by the Wits PGCE student teachers can be video recorded and the captured responses maybe used for purposes of this study only. YES/NO

Informed Consent

I understand that:

- my school's name and learners' names and information will be kept confidential and safe and that the names and identities will not be revealed.
- The learners in the classes taught by Wits PGCE student teachers can ask not to be audio/video recorded.
- all the data collected during this study will be destroyed within 3-5 years after completion of this research project.

Sign_____ Date_____

Appendix O: Consent form to the Supervising teacher

LETTER TO THE SUBJECT TEACHER

DATE:

Dear Subject Teacher,

My name is Mamohato Violet Makhechane, a PhD student in Science Education in the School of Education at the University of the Witwatersrand. I am conducting research on the development of (senior phase/FET) PGCE student teachers' pedagogical reasoning ability for specific science topics. The research aims at improving special teacher knowledge for teaching science topics efficiently. The knowledge is called Topic Specific Pedagogical Content Knowledge (TSPCK). The approach of TSPCK is considered valuable by the science education community, nationally and internationally in improving teacher effectiveness in teaching for understanding.

The research is at a stage where I need to evaluate the effectiveness of teaching by the student teachers. I would like to use this opportunity to evaluate the quality of their teaching to your grade 11 and 12 physical science classes. In order to do this, the student teachers will have to teach them for at least two lessons in a selected topic. Their lessons will be video/audio recorded to capture their TSPCK in action. I will stand behind the learners in the class to video/audio record the moves and actions of the student teacher and the learners during the lesson. This will allow the research do explore through this observations and records, the ability of the teacher to transform content for accessibility by the learners.

I therefore need your permission to carry the above laid activities. I am aware that consent is also needed from the school Principal hence attached. I have also attached to this letter, approvals from GDE and from Wits University Ethics committee. Participation in this study is voluntary. The learners' responses that will be captured through the records during the lesson observations will not be made public and will be but accessible only to me and my supervisor. Effort will be made to avoid capturing of learners who have not consented and if captured unavoidably, their faces will be screen blocked. The recordings will be kept confidential and saved under password. The learners' names, school's name and identities will be kept confidential at all times in all my academic writings. The privacy of the learners will be maintained in all published and written data resulting from this study. If a need arises that we need to quote from the recordings and a learner's name was mentioned by the student teacher, a pseudo name will be assigned to the person quoted.

Your learners will neither be advantaged or disadvantaged in any way. They will be reassured that they can withdraw their permission to be video recorded at any time during this research study without any penalty. There are no foreseeable risks in participating and your learners will not be paid for participating in this study.

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

Thank you for your help.

Yours sincerely,

Name: Mamohato Violet Makhechane

Address: Wits University, Education Campus, Science and Education Technology Division, 27 St. Andrew Road, Parktown.

Email: 1304503@students.wits.ac.za

Phone Number: 0607732490

SUPERVISING TEACHER'S CONSENT FORM

Please fill in below as an indication of your approval, allowing your school and learners to participate in my voluntary research project called Topic Specific Pedagogical Content Knowledge.

I, _____ give my consent for the following:

Circle one

I agree that my school may participate in this research study and that all the recordings be used only for this research. YES/NO

I agree that the learners taught by the Wits PGCE student teachers can be audio recorded and the captured responses maybe used for this study only. YES/NO

I agree that my learners taught by the Wits PGCE student teachers can be video recorded and the captured responses maybe used for this study only. YES/NO

Informed Consent

I understand that:

- my school's name and learners' names and information will be kept confidential and safe and that the names and identities will not be revealed.
- The learners in the classes taught by Wits PGCE student teachers can ask not to be audio/video recorded.
- all the data collected during this study will be destroyed within 3-5 years after completion of the research project.

Sign_____ Date_____

Appendix P: Consent form to the Parents

LETTER TO THE PARENTS

DATE:

Dear Parent,

My name is Mamohato Violet Makhechane, a PhD student in Science Education in the School of Education at the University of the Witwatersrand. I am conducting a research study on the development of (the senior phase/FET) PGCE student teachers' Pedagogical reasoning ability for specific science topics. The research study aims at improving special teacher knowledge for teaching science topics efficiently. The knowledge is called Topic Specific Pedagogical Content Knowledge (TSPCK). The approach of TSPCK is considered valuable by the science education community, nationally and internationally in improving teacher effectiveness in teaching for understanding.

The research is at a stage where I need to evaluate the effectiveness of teaching by our student teachers posted to your child's school for a teaching experience this academic session. During this time, student teachers, under the guidance of a practicing teacher, are assigned to teach various classes in the Senior/FET phase. I would like to use this opportunity to evaluate the quality of their teaching. In order to do this, at least three of the student teacher's lessons will be video/audio recorded to capture their ability to teach for understanding. I will stand behind the learners in the class to video/audio record the moves and actions of the student teacher and the learners during the lesson. This will allow the research study to explore through these observations and record, the ability of the teacher to transform the content for accessibility by the learners.

I therefore need your permission to carry out the above-mentioned activities. All the recordings from your child will remain confidential. They will be used only by me and my research supervisor. The recordings will be kept confidential and saved under password. Your child's name and identity will be kept confidential at all times and in all academic writing about this study. The privacy of your child will be maintained in all published and written data resulting from this study. If a need arises that we need to quote from the recordings where your child's name was mentioned, a pseudo name will be assigned instead not your child's real name.

Your child will not be advantaged or disadvantaged in any way. He/she will be reassured that they can withdraw their permission to be video recorded at any time during this research without any penalty. There are no foreseeable risks in participating and your learners will not be paid for participating in this study.

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

Thank you for your help.

Yours sincerely,

Name: Mamohato Violet Makhechane

Address: Wits University, Education Campus, Science and Education Technology Division, 27 St. Andrew Road, Parktown.

Email: 1304503@students.wits.ac.za

Phone Number: 0607732490

PARENT'S CONSENT FORM

Please fill in below as an indication of your agreement to allow your child to participate in my research project.

I, _____ give my consent for the following:

Circle one

I agree that my child should participate in the research study and all the recordings be used for this research only
YES/NO

I agree that my child should be audiotaped and that the audio recordings will be used for this study only

YES/NO

I agree that my child should be videotaped and that the videotapes will be used for this research only
YES/NO

Informed Consent

I understand that:

- my child's name and information will be kept confidential and safe
- my child can ask not to be audio/ video recorded
- all the data collected during this study will be destroyed within 3-5 years after completion of the project.

Sign_____ Date_____

Appendix Q: Consent form to the Learners

LETTER TO THE LEARNERS

DATE:

Dear Learner,

My name is Mamohato Violet Makhechane, a PhD student in Science Education in the School of Education at the University of the Witwatersrand. I am conducting are search study on the development of FET Physical science PGCE student teachers' Topic Specific Pedagogical Content Knowledge.

The student teacher taking your class for physical science lessons has been exposed to a new approach of preparing and teaching science topics. The aim of this new method is to ensure that concepts are explained in a manner that you can understand. During the teaching practice, the student teacher's lessons will be video recorded. The recordings are intended to focus on the actions and moves of the student teacher as well as your contributions as a learner during the lessons. I will stand at the back of the class to video record all that happens during the lessons.

I therefore need your permission to carry the above-mentioned activities. All the recordings and responses from you during the recordings will not be made public. They will be used by me and my research supervisor only. The recordings will be kept confidential and saved under password. Your name and identity will be kept confidential at all times and in all academic writing about this study. If a need arises to quote from the recordings, a pseudo name will be assigned to the person, and no real names will be used. You will not be advantaged or disadvantaged in any way. You can choose to withdraw your permission to be video/audio recorded at any time during this research study without any penalty. There are no foreseeable risks in participating and you will not be paid for participating in this study. However, you are allowed to refuse permission to be video/audio recorded during the lessons if you wish to do so. In such a case, all efforts will be made to electronically block your voice and physical recording. There will be no penalty in any form to you for refusing to be recorded. The value of the recordings and responses to the questionnaires is to improve the way Universities prepare and train future science teachers.

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

I look forward to hearing from you and wish you an enjoyable experience with our student teacher.

Thank you for your help.

Yours sincerely,

Name: Mamohato Violet Makhechane

Address: Wits University, Education Campus, Science and Education Technology Division, 27 St. Andrew Road, Parktown.

LEARNER'S CONSENT FORM

Please fill in below as an indication of your agreement to participate in my research project.

I, _____ give my consent for the following:

Circle one

I agree to participate in the research study and my responses will be used for this research only

YES/NO

I agree to be audiotaped during the classroom teaching YES/NO

I agree to be videotaped during the classroom teaching YES/NO

I agree that the audiotapes/videotapes should be used for this research only. YES/NO

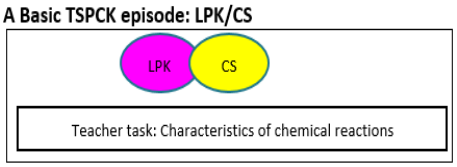
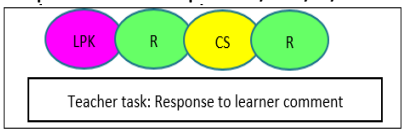
Informed Consent

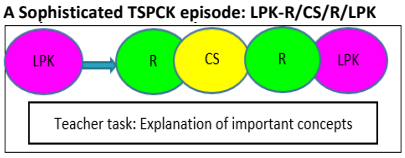
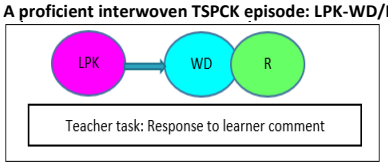
I understand that:

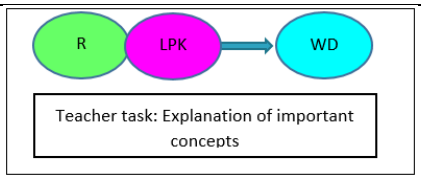
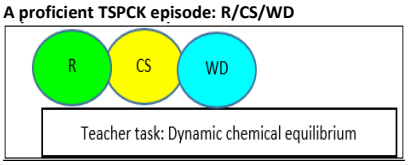
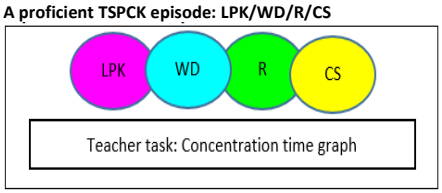
- My name and information will be kept confidential and safe and that my name and that of my school will not be revealed.
- I can ask not to be audiotaped and/or videotaped.
- All the data collected during this study will be destroyed within 3-5 years after completion of my project.

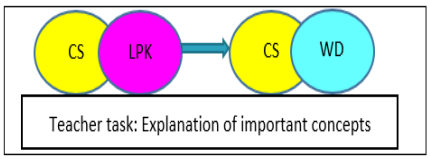
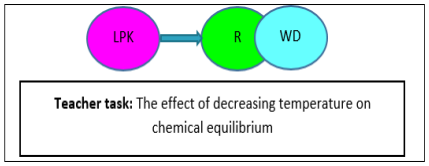
Sign_____ Date_____

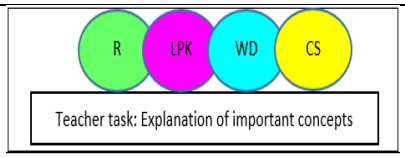
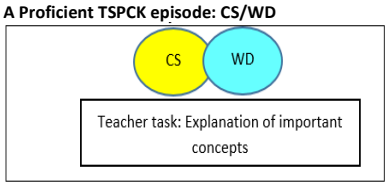
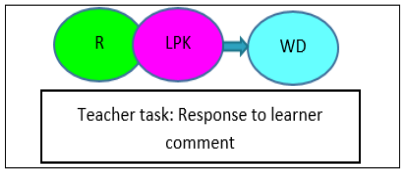
Appendix R: A detailed analysis of Noma's lesson

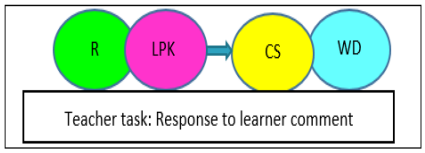
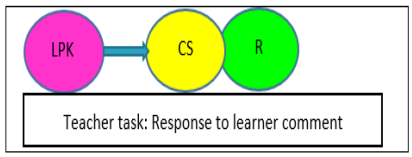
Episode Extract	Qualitative in-depth analysis
Review on characteristic features of chemical reactions: 0-3mins **Noma:** What can you tell me about particle? Do you know anything about particles? **Stds:** Yes **Noma:** But what happens during a reaction? What do you think happens to them during a reaction? **One std:** They bond and react… **Noma:** They bond…yes, they react together. What about that bonding? What can you talk about, about that bonding that happens when particles start to react? **One std:** Some bonds are stronger, and some bonds are weaker… **Noma:** But what makes some to be strong and what makes some to be weaker? **One std:** The forces between them **Noma:** The forces between the particles, what else? **Another std:** energy **Noma:** Thank you, that's what I was looking for, energy. Yes, he spoke about energy. Obviously, particles in order for particles to react, they need to have energy, don't you think? So, what do you think will happen? **One std:** We can increase the temperature. **Noma:** Thank you. So now, two things that can happen; you can either get a reaction that is endothermic, or you can get a reaction that is exothermic. An endothermic reaction, this is where the particles in actual fact, do not have a lot of energy, neh? So, for that reaction to happen, energy needs to be put in, but exothermic reactions give out energy instead.	**Overview:** General probing by Noma to check if students know about characteristics of chemical reactions. **Qualitative in-depth analysis:** Noma probes learners around to their understanding of how reactions happen which is evidence of learner prior knowledge (LPK). She then mentioned that reactions that need to absorb energy in order to occur are endothermic while those that release energy are exothermic. This is an aspect of curriculum saliency (CS). In this teaching segment, there is an interaction between two TSPCK components as displayed in the TSPCK map below. **A Basic TSPCK episode: LPK/CS** 
Introducing the types of systems: 3-10mins **Noma:** Ok, with reactions, where do you think they take place most of the time? **One std:** I think they happen everywhere **Noma:** Everywhere? Yes, I agree. So, if they take place everywhere, what kind of a system do you think it is? **One std:** Open **Noma:** Open, so what is an open system? … So, you are saying that reactions take place in an open system. So, what is an open system? **One std:** Atoms can be shared **Another std:** They can be transferred… **Another std:** Some reactions go in reverse **Noma:** Writes *reverse and open system on the board*… you mentioned reverse and an open system, what else? **Stds:** Silence **Noma:** Ok, now when you are having the reactants right, reactant A and reactant B, now you put them in a test-tube or beaker and you shake (demonstrates the movement with a beaker), when is it an open system when they react? Ok, I take a lid and I cover it (closes the beaker) … **Stds:** It is a closed system **Noma:** It is a closed system. So now the question is what is an open system? What is an open and what is a closed system? **One std:** A reaction that happens in the air… **Noma:** A reaction that happens in the air? **Another std:** I think a closed system is a reaction that happens in a closed environment… **Noma:** Let us say for example I am boiling water in this beaker, and it is not covered with anything. So, whatever is emitted here; the vapor, it interacts with the environment right. It escapes to the surrounding outside the beaker. But with a closed system, whatever that is emitted here, from the reaction, is kept within that environment. The vapor cannot leave because we have the lid that stops it from escaping	**Overview:** Probes learners to have them explain and differentiate between open and closed systems which they struggle to expound on. Demonstrates the two types of systems using an open and a closed beaker enclosing arbitrary reactions and emphasizes that reactions that happen in open systems lose mass to the surroundings, whilst those in the closed systems do not lose mass, but it is enclosed within the system. Makes an analogy of boiling water in a closed beaker versus an open beaker. **Qualitative in-depth analysis:** To introduce types of systems in which reactions can take place in, Noma probed for learner knowledge on the aspect (LPK). When she realized that students struggled to understand her questions, she demonstrated to them using an open and a closed beaker (R), to help them differentiate between the two types of systems. She emphasizes on the important features regarding open and closed systems (CS) using an analogy of boiling water in each to explain (R). Three different TSPCK components are interactively used in this episode with one of the components repeating as displayed in the TSPCK map below. **A Sophisticated TSPCK episode: R/ LPK /CS/R** 

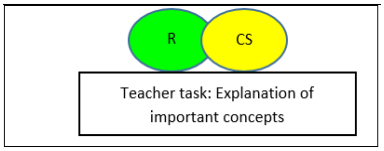
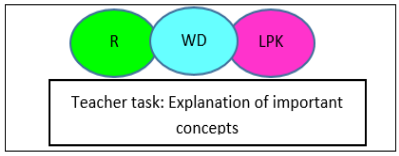
<u>The reversibility of chemical reactions:</u> 10-17mins **Noma:** … Ok, let us talk about reversible reactions…for example, where do you think this reversibility takes place? What kind of a system? **One std:** Open **Noma:** Ok, you are saying open. Why are you saying open? **Same std:** Eh, ma'am gases can be compressed to maybe, eh let us say water, it can be converted into gas, and later into liquid… **Noma:** Do you think it is an open system? **Same std:** I think so because it happens in … **Other stds:** No, it is a closed system **Another std:** I think it is in a closed system because it is in a controlled environment, so you know what reacted and you can reverse that. **Noma:** And you can reverse that right… So, give me a definition of what reversing means in chemistry… **One std:** It is maybe when a reaction is undone… **Noma:** Let us say you have two reactants reacting, where A and B react to form C and D, then C and D also react to make A and B. Do you see? (Representing the reverse with a two headed arrow on the equation). I know from grade 9, you were only doing it like this neh (draws a single headed arrow). Where you find that most of your reactions would be going only in one direction. So, when a reaction happens in a closed system, reactants combine to form products, and products also react to form back the reactants. Those types of reactions are called reversible reactions. They are reversible because reactants combine to form products, and products form and form, and those products also react and form reactants. So, a simple scenario can be a case of water. You have got your class beaker, pour your water and cover it (doing hand demonstration). It will evaporate but it doesn't go any further because it can't escape. The gases cannot escape. There is cooling that happens, and then it drops off as liquid water. The cycle continues and continues and never ends. After some time, the reaction will reach chemical equilibrium. Ok, this does not only happen with water. It happens with a lot of reactions too.	**Overview:** Introduction of the reversible nature of chemical reactions using arbitrary symbolic equations and a change of phase of water for emphasis. Emphasized on the continuous nature of reversible reactions, highlighting that they never end. **Qualitative in-depth analysis:** She introduced the concept of reversibility by tapping on students' understanding of what reversible reactions entail (LPK). She the continued by referring students to the chemical equations/reactions that were discussed earlier in the lesson. Chemical equations are examples of symbolic representations (R). She puts an extra emphasis that reversibility happens in closed system; an aspect of curriculum saliency (CS). Providing a scenario of water evaporating and condensing back to a liquid (R) to emphasize that this is a continuous process where one does not have to stop before the other begins. This is evidence of learner prior knowledge in the form of a misconception (LPK). A four component TSPCK episode evidently interacting in an explanation as displayed on the TSPCK map with LPK linearly linked to other interwoven components. **A Sophisticated TSPCK episode: LPK-R/CS/R/LPK** 
<u>The rate of reactions at equilibrium-rate time graph:</u> 17-25mins **One std:** Madam how do we define chemical equilibrium then? **Noma:** Remember we are dealing with reversible reactions, right. Now what happens is, when this reaction reaches chemical equilibrium, the rate of the formation of the product will be the same as the rate of the formation of the reactants. So. do you understand when I say the rate? **Stds:** Yes **Noma:** What did I mean? **One std:** The speed… **Noma:** The speed at which? **Same std:** The products form reactants and reactants form products. **Noma:** The speed at which they react. So that is what we call chemical equilibrium. So, two reactions, forward and reverse are taking place at the same speed, but we say rate not speed. So, the rate at which reactants form products is equal to the rate at which the products are combining themselves to give us reactants. So as the product is being formed, the reactant is being formed. Do you understand what I am saying? Stds: Yes Noma: (Draws the rate versus time graph on the board for formation of N_2O_4 from NO_2). So, the rate of the forward reaction is equal to the rate of the reverse reaction as seen here where the graph is flat. This is a rate time graph that we use to show that rates are equal at equilibrium	**Overview:** Defining chemical equilibrium using the rates of forward and reverse reactions; using the rate versus time graph on formation of N2O4 from NO2 and specifically indicating which part of the graph represents chemical equilibrium. **Qualitative in-depth analysis:** Triggered by a learner question (LPK), Noma explains chemical equilibrium in terms of rates of forward and reverse reactions, which are equal. This is a concept that is not easy for students (WD). She then emphasizes further on the nature of rates by providing a rate graph (R) and indicates specifically which area within the graph represents chemical equilibrium. Three components are evidently interacting in this episode as displayed on the TSPCK map below. **A proficient interwoven TSPCK episode: LPK-WD/R** 
<u>Rate versus time graph explained:</u> 25-33mins Noma: So, let us study this graph further; the rate versus time graph that I just drew. We have our reactants, and we have our products, and we are talking about chemical equilibrium. Can someone explain what is happening in this graph? One std: It is equal Noma: What is equal? Another std: Both Noma: What is "both"? Another std: The formation… Noma: The formation of what…we spoke about that. Now I am saying explain what is happening in this graph. Another std: Is not it that the speed ma'am… Noma: What about the speed? Same std: The speed of a reaction, is it decreasing, because madam it's getting downwards. Another std: Can I please break it down? Yeah, the dots, eh, the graph below is showing the reactant part… Noma: Are you saying this is the reactant part?	**Overview:** In this segment, Noma probed students to explain the change in rates within the rate versus time graph, which they failed to do. Noma then explained the graph from the beginning until chemical equilibrium is achieved where the forward reaction rate is equal to the reverse reaction rate. **Qualitative in-depth analysis:** This segment begins with a display of a rate time graph (R) which the group has touched on prior to this discussion. Noma then asked students to explain the graph, probing them for the correct responses, but students could not describe the graph (LPK). In response to this, Noma explained the rate changes herself in different sections of the graph until chemical equilibrium is achieved where the rate of forward and reverse reactions are equal (WD). Three components are evidently interacting in this episode as presented on the TSPCK map below. The episode has both linear and interweaving components. **A Proficient TSPCK episode: R/LPK-WD**

Same std: Yes, because the time there shows that they are increasing. So, it shows the time and rates, they are increasing. So, I think it is the reacting part. And then the above graph it shows the products Noma: Ok let me explain. I think you guys are confusing a lot of things. Ok, what did we say about chemical equilibrium and a definition of it? One std: The rate at which the product is formed, and the reactants are formed is the same… Noma: It's the same… The first part, we have got the NO2, it's being used up. When something is a reactant, isn't it that it is being used up? You will get less and less of that; don't you think? Stds: Yes ma'am. Noma: Do you understand, you get less and less of that, less and less of that (demonstrating that on the graph). What about the product, it is increasing? There was not anything in the beginning remember. You had the reactant (referring to the chemical equation on the board), do you understand? So, when we look at this graph, we see that the rate at which reactants form into products is decreasing. This is why we see the slope for reactants going down. But the rate of formation of reactants from products increases with time which is observed in the increasing slope of the products. We then get to this point where now the rates are equal, which we said is show now that our reaction is at chemical equilibrium. Are we clear now? Stds: Yes ma'am.	
<u>The dynamic nature of chemical equilibrium:</u> 33-35mins **Noma:** Isn't it that in this reaction (formation of N_2O_4 from NO_2), or when water evaporates and then condenses, the forward reaction happens at the same time as the reverse reaction? **One std:** Can you say it again? **Noma:** The forward reaction happens at the same time as the reverse reaction. So, we call this a dynamic process. Because both reactions, the forward reaction that forms products and the reverse reaction where products are breaking into reactants are continuously happening at the same time, they call this process a dynamic chemical equilibrium. It is because the reactions are happening at the same time, they are happening together, and it is a continuous process. So, when we reach a point where these two reactions that are simultaneously happening, happen at the same rate, we call that dynamic chemical equilibrium.	**Overview:** Explaining the dynamic nature of chemical equilibrium **Qualitative in-depth analysis:** Referring learners to the reaction on the board and a case of water changing phase (R), Noma reminds students that in reversible reactions, both forward and reverse reactions occur simultaneously as discussed in the previous sections (CS). She explains this further showing that the simultaneous occurrence of the two reactions is referred to as a dynamic process (WD); hence the stage where rates of reactions are equal is referred as dynamic chemical equilibrium. This is a three component TSPCK episode with the 3 components evidently interacting in an interwoven fashion as displayed on the TSPCK map below. **A proficient TSPCK episode: R/CS/WD** 
<u>The nature of concentrations of reagents at equilibrium-concentration time graph:</u> 35-42mins **Noma:** what do you think happens to the concentrations at this point, at a chemical equilibrium position? **One std**: It changes **Noma:** Do you all think it changes? **Another std:** It stays the same **Noma:** They stay the same. The concentrations stay the same, they do not change, they remain constant. The concentrations can also be demonstrated on a graph like we did with rates. (Draws a concentration time graph for an arbitrary reaction). First of all, we have the concentration of reactants decrease remember because they are reacting and forming products. So, their concentration decreases like it is showing in this graph. Do you see the slope is decreasing? Then we started with no products, this is why we start at the bottom, then products increase, increase and increase, until we get here, where the lines are not changing. So, can someone tell me where this equilibrium is going to take place? Do you remember the graph that we had initially? But that one was rate and time right, (draws the rate graph on the board)? Then we had something like this and something like that? And I said somewhere here, that's where equilibrium starts right? What about this one (concentrations versus time graph)? Which part shows chemical equilibrium? **One std:** Eh, I think equilibrium is here, where the concentrations are constant (draws a vertical line where they are constant). **Noma:** Absolutely, this is where the concentrations are constant, and that shows chemical equilibrium.	**Overview:** The concentration versus time graph used in explaining how the changes in concentrations of reactants and products happen throughout the reaction, until dynamic chemical equilibrium is achieved where concentrations of both reactants and products remain constant. **Qualitative in-depth analysis:** Noma begins this teaching segment by probing on learners' knowledge (LPK) with regards to the nature concentrations of reagents at chemical equilibrium. Noma commends the response that they stay the same and goes further to show that they do not change but remain constant (WD). She then presents a concentration time graph of an arbitrary reaction (R) explaining how concentrations change across, until chemical equilibrium is achieved. An emphasis on the changes brought an aspect of curricular saliency (CS). Four components are evidently interacting in an interwoven fashion in this episode as displayed on the TSPCK map below. **A proficient TSPCK episode: LPK/WD/R/CS** 
<u>Introducing factors affecting chemical equilibrium- effect of temperature explained further:</u> 42-50mins **Noma:** Ok, let us move then to the factors that affect the chemical equilibrium, the dynamic chemical equilibrium. What do you think are those factors?	**Overview:** Introducing factors that affect chemical equilibrium; The effect of temperature explained, and emphasis made on the need to know whether the reaction is endothermic or exothermic before deciding on the effect that the change in temperature will have on chemical equilibrium.

One std: Temperature **Noma:** Temperature, what else? **Another std:** Pressure **Noma:** Pressure… **Another std:** Concentration **Noma:** Did you say concentration? **Stds:** Yes **Noma:** Let us begin with change in temperature. What do you think will happen when you increase temperature? **One std:** When you increase the temperature, it is going to reach dynamic equilibrium quicker. **Noma**: So currently the normal reaction, the forward reaction is an exothermic reaction right, but the minute you put/increase the temperature, it is gonna favor the endothermic side of this reaction. Do you understand? **Stds:** Why? **Noma:** So, when we change temperature, before you think about the effect on chemical equilibrium, you have to know which reaction is endothermic and which one is exothermic. So now we are saying the forward reaction is exothermic right. And we said that we are increasing temperature, so which reaction will be favored? **Stds:** Silence **Noma:** We favor the reverse reaction. The endothermic reaction is favored. So, if we reduce the temperature, the forward reaction will be favored which is the exothermic one.	**Qualitative in-depth analysis:** In this teaching segment, Noma introduces students to three factors that affect chemical equilibrium (CS). She the taps on learners' prior knowledge on the effect of change in temperature of the system (LPK). This she explains further by emphasizing on the sequence in which to follow before deciding on the effect (CS). The then uses the arbitrary reaction (R) to explain the effect of change (WD). Three different TSPCK components are evidently interacting in this episode with one of the components repeating. The episode is presented in the TSPCK map below. **A sophisticated TSPCK episode: CS/LPK-CS/WD** 
<u>Re-emphasis on the effect of temperature on chemical equilibrium:</u> 50-57mins **One std:** Ma'am I don't understand how you know which reaction is being favored? I am confused… **Noma:** Are you confused by the last part or the whole endothermic and exothermic reactions? Ok, let me make an example. Let us say the temperature for this reaction was 25˚C where you find the production of your reactants and products happening at the same time at that temperature. Decrease the temperature by 2˚C, then it is no longer in equilibrium. Do you agree with me? **Stds:** Mmmm **Noma:** So which reaction is going to be favored? So, we can make an example with pushing someone against the wall. She will feel pressed and what will she do? She will probably try to push me away as well. So, she needs to find her balance again. She needs to find her equilibrium. I came to push her, but then it means her equilibrium was disturbed. So, for her to find balance and go back to that equilibrium, she needs to move right? So, she moves where, towards where I am at. She pushes me away. When I am pushed away, then she maintains her equilibrium. So, under normal circumstances, this reaction is exothermic. So, this means when this is being produced, at the same time this is being produced (reactants and products respectively) at that temperature. Let us say 25˚C. But then I minus 2˚C but I still use this thing… the forward reaction was exothermic. So, what is going to happen? **One std:** So, what happens to the temperature? **Noma:** It is going down… Do you understand what I am saying? What is exothermic? Heat is emitted. So, when you reduce the temperature of the system…then the reaction is going to move in which direction, the direction which produces that lost energy. Which means the forward reaction will still be favored, which is the exothermic reaction.	**Overview:** Noma emphasizes on the effect of temperature changes on chemical equilibrium, by discussing more on what reducing temperature does to the system. When learners got confused, she used a familiar analogy to help them understand the concept. **Qualitative in-depth analysis:** To put more emphasis on the effect of change in temperature on chemical equilibrium, Noma begins by probing students with respect to what decreasing the temperature of the system would do to the reaction (LPK). When one student seemed not to understand how one gets to the conclusion of how the system reacts to the disturbance, Noma used an analogy of pushing someone against the wall and how the person would react to the push by pushing back in order to maintain their balance (R). This provided a sense of the reaction reacting in a way that opposes the disturbance which he then showed later on the discussion that lowering the temperature will have a system favoring a reaction that increases the removes substance, an exothermic reaction. This is a concept that students find difficult to conceptualize (WD). Three components are evidently interacting in this episode in both linear and interwoven fashions. The component interactions are displayed in the episode below. **A proficient TSPCK episode: LPK-R/WD** 
<u>The effect of pressure changes on chemical equilibrium:</u> 60-65mins **Noma:** The second effect is that of pressure. (Writes a reaction; $N_2O_4 \leftrightarrow NO_2$). Remember that these are both gases. What do you think happens to the system? Go back to volume. When you go back to volume, go back to collision, and then you will know the answer. Think about it. So, you apply pressure on something, when you increase the pressure of gases, what happens to the volume? **Stds:** Decreases **Noma:** It decreases. What do you think happens to the particles inside? **Stds:** They collide more **Noma:** They collide more. So, what do you think of that reaction? So, what do you think, which reaction is going to be favored here? **Stds:** Silence **Noma:** It favors the one with fewer moles. There is too much pressure. There is too much pressure. You got confused neh (referring to one student)? **Std:** Yes **Noma:** So, pressure does what? When you put too much pressure…? **Stds:** Increases collisions, decreases volume…	**Overview:** Reminds learners of the relationship between pressure and volume as learned in other topics. The effect of an increase in pressure is then discussed. **Qualitative in-depth analysis:** The segment's discussion is on the effect of change in pressure which begins with a display of a chemical equation (R). Noma then links this to students' previously learned knowledge between pressure volume, by asking students what the effect of increasing pressure is on both volume and the collision rate of the gas particle (LPK) and explained the effect of increasing pressure to gaseous reactions where the reaction attempts to reduce the added pressure by favoring a reaction that produces less moles (WD). She continued by explaining further that an increase in pressure means a decrease in volume which bring more moles into a smaller space hence the reaction that produces less moles will be favored to reduce the pressure. This emphasis brings an aspect of CS into the teaching segment. **A Sophisticated TSPCK episode: R/LPK/WD/CS**

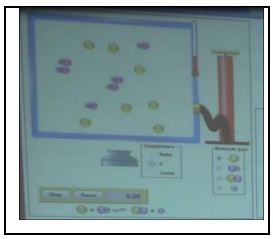
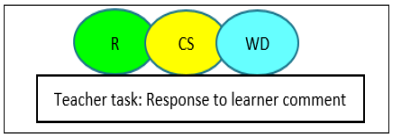
Noma: Normally it decreases the volume. So, imagine when you have a system like this and then you squeeze it. So, you put a lot of pressure on this system, what is going to happen? It is going go to where it is less because it needs to balance again. There is too much pushing from this side. Do you understand, it is too much, so the reaction will want to produce less moles to balance the pressure. So, the forward reaction is favored. The favored reaction is the one that uses the added substance, so that the pressure is less after. And then, when you decrease your pressure, it is vice versa. So, increasing pressure favors production of less moles and the decrease in pressure favors production of more moles.	
<u>Introducing the Le Chatelier's principle:</u> 65-72mins **Noma:** Now, before we talk about concentration, when any of these factors are changed, there is something that happens to the reaction. There is something that the reaction wants to do. What do you think the reaction wants to do? **Stds:** Silence **Noma:** So, there is this principle by the Le Chatelier's. Now this principle is saying, when our reaction will be in equilibrium and you apply this disturbance to your reaction; that reaction is going try to regain equilibrium again. Do you understand? That is what the principle is all about. And this principle it applies normally when it comes to your dynamic equilibrium. So, when it is disturbed, the reaction will re-instate a new equilibrium. To re-instate a new equilibrium, how does it do that? When it re-instates a new equilibrium? Stds: Silence Noma: It will favor the reaction that opposes that disturbance. It favors the reaction that opposes the disturbance. So, there is a disturbance in the system One std: So, the system opposes the disturbance? Noma: For example, we said when we put in a lot of pressure, it will favor which reaction? Stds: The one with the less moles Noma: The one with the less moles. You decrease the pressure; it will do the reverse. So that is why they are saying when the equilibrium in a closed system is disturbed by the temperature, pressure or concentration, the system will therefore reinstate a new equilibrium. And how does it do that, by favoring that reaction which actually opposes the disturbance.	**Overview:** Explaining the Le Chatelier's principle to the students, by indicating that a reaction that opposes a disturbance is favored, and later the whole reaction reinstates a new chemical equilibrium position. Provides an example of increasing pressure in a reaction, where the reaction will react to reduce the disturbance by favoring the side that produces less moles of gas as a way of reducing pressure to the system. **Qualitative in-depth analysis:** In this segment, Noma introduces learners to the Le Chatelier's principle; an important principle used for predicting the effect of a disturbance to a reaction at chemical equilibrium (CS), which states that a system always reacts to oppose the added disturbance. She emphasized this with an example of change in pressure, explaining how the system reacts to the change (WD). The episode shows an evident interaction between two TSPCK components as displayed on the TSPCK map below. **A Proficient TSPCK episode: CS/WD** 
<u>The effect of change of concentration of one reagent on chemical equilibrium:</u> 72-78mins **Noma:** Moving on to concentration. (Writes an arbitrary reaction on the board; A + B ↔C + D). Let us say that you increase B, what will happen? Think about what Le Chatelier's Principle says? **One std:** A system will try to oppose the disturbance. **Noma:** So how do you think the disturbance is going to be opposed? Where do you think the reaction is going to shift? **One std:** To the left **Noma:** Remember, when these two are reacting, for example let us say, one of this will react with one of that, to give you maybe two of this and two of that (A + B ↔2C) and this reaction is at equilibrium. Now what do you do, you are saying, I am gonna increase the concentration of B. Do you understand? So, what is going to happen is a lot of instability here, don't you think? So, this reaction is going to push more towards the product side, to make more of C so that there can be stability again this side (the reactant side). So, to oppose an increase of this, it then shifts towards the right, forming more products; this way the disturbance caused by adding more of B is reduced because it is now reacting to form more of C. After some time, the reaction will form or reach new chemical equilibrium. Remember we said after a disturbance, a reaction will always re-instate another equilibrium. So now make an example here with the actual reaction. Let's go back to this now (formation of N_2O_4 from NO_2). What do you think will happen if I increase the concentration of N_2O_4? It will favor which side? **Stds:** The reactant side **Noma:** Yes, a reversible reaction will be favored because we have increased the concentration of a product. So, do you see the trick? The reaction tries to oppose the disturbance by favoring the reaction that reduces that disturbance. This way the reaction can get stable again and re-gain another equilibrium state.	**Overview:** The effect of change in concentration on the equilibrium position. Noma used both an arbitrary and the actual chemical reaction to explain the effect of changing the concentration of a reactant. **Qualitative in-depth analysis:** The segment begins with a display of a symbolic equation (R) to explain the effect of change in concentration on chemical equilibrium. Learners are then requested to apply their understanding of the Le Chatelier's principle to explain the effect of concentration change (LPK). Noma emphasizes on the effect of change using a different chemical equation, also highlighting that the reaction will always re-instate a position of chemical equilibrium even after a disturbance (WD). Three components are evidently interacting in this episode as displayed in the TSPCK map below. **A proficient TSPCK episode: R/LPK-WD** 
<u>An evaluation on learner understanding of the effect of concentration:</u> 78-88mins **Noma:** Presents an equation on the board; $2SO_2 + O_2 \leftrightarrow 2SO_3$. I need someone to come and draw a concentration time graph that shows an effect of a decrease in temperature for this reaction, which is at equilibrium, assuming that the forward reaction is exothermic. **One std:** Draws the graph, exothermic will be favored. **Noma:** Do you all agree with him? Who agrees that it is gonna favor the production of the products? What happens when we increase the temperature? **One std:** It will favor the reverse	**Overview:** The segment acts as an evaluation episode that attempts to check learners' understanding of the effect of temperature on the reaction at a state of chemical equilibrium, and how this change can be presented on a concentration versus time graph. **Qualitative in-depth analysis:** The segment begins with a display of an equation for a chemical reaction that is assumed to be at equilibrium (R) which learners are to draw a concentration time graph for (LPK). Most students however appeared to be confused when asked

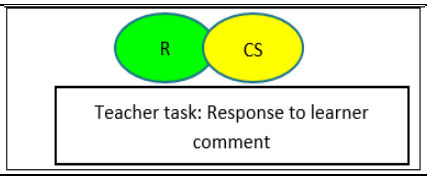
Noma: The reverse, why? I want you guys to think of it in terms of collision… Remember this is an exothermic reaction. Do you understand what I am saying? **One std:** What was the original question? **Noma:** My question was the temperature has actually been decreased. **Stds:** Sound confused **Noma:** Guys just look back at the example that I gave you; then the example that I said to you when you increase the temperature. What happens on an exothermic reaction? **Stds:** It will favor the endothermic reaction. **One std:** Which side is that? **Noma**: Ok guys, let us go back… What are the properties of the exothermic reaction when it comes to collision? **One std:** There are more collisions **Noma:** There are more collisions. So, this reaction, there are more collisions; decrease the temperature…so it means we are gonna move to which side, that way (indicating the forward reaction). **Stds:** Ooooh **Noma:** You got it? Who did not get it? You did not? **One std:** yes **Noma:** Listen, an exothermic reaction, what comes to mind? **One std:** It happens spontaneously **Noma:** But what happens to the particles? **One std:** Collisions are more **Noma:** There will be a lot of collisions that occur spontaneously, and the reaction itself produces heat energy, so you decide to increase the temperature to that, what happens? This is now equilibrium, there is a lot of collisions happening, from this to that (reactants to products), this is why it is then exothermic. If the temperature is increased, what do you think is gonna happen? Where do you think there is gonna be a lot of pressure? So already it is happening spontaneously, increase the temperature now…what will happen to the particles? **Same std:** It will move to the left. **Noma:** The left, and what do you mean by the left? Which reaction is favored? **One std:** The endothermic reaction. **Noma:** Do we all understand? Remember we said a system tries to oppose the disturbance and, in this case, increasing temperature causes a disturbance. So, a reaction that removes or uses that heat is favored, which is the endothermic reaction.	how the graph was obtained. Noma then explained this further through probes by indicating that the forward reaction is exothermic, which means it is spontaneously happening and produces heat energy as one of the end products (CS), hence if the temperature is increased, the reaction that reduces the added temperature will be favored, which is an endothermic reaction (WD). Four TSPCK components are evidently interacting in this episode as displayed on the TSPCK map below. The episode displays both linear and interweaving components. **A sophisticated TSPCK episode: R/LPK-CS/WD** 
<u>An evaluation on the effect of pressure:</u> 88-97mins **Noma:** I need someone to draw a graph for a decrease in pressure for the reaction between Sulphur dioxide and oxygen above. **One std:** Went to the front to draw the concentration versus time graph… **Noma:** (As the student writes the axis name), you can write the moles (referring to the side where the students wrote concentration), but this is fine. Now can you explain how the graph is going to be affected by this increase in pressure? **Same std:** So, when pressure increases, the volume is gonna decrease, therefore there is gonna be more collisions. And then this side has more moles (the reactant side) than this side with only two moles. So, this reaction will favor the side with less moles. So, the reaction will move this way (towards the product side). **Noma:** It will favor the production of the product. Do we agree? **Stds:** yes **Same std:** So, the products are gonna increase (draws the graph). So, these are the reactants, and these are products (presents/denotes that on the graph). **Noma:** So, theoretically you are correct, but the graph is not correct. Who can come and draw the graph?... So, she is saying you are gonna have less of the reactants and more of the products, right? **Stds:** Yes **Noma:** Remember it is concentration versus time guys neh? **Stds:** Yes **Second std:** Draws the graph… **Noma:** So, listen guys, the reactants become less… and more products are forming right? **Same std:** Draws the opposite (increase in reactants and decrease in products) … **Noma:** But are the products deceasing here? Ok, let me help you. Ok, I agree with her partially. So, this is the initial, remember I said that it was at equilibrium. So, you are having this at some point right, concentrations are all constant at equilibrium? Then it changes due to a disturbance caused by an increase of pressure. You said more of the products are being formed right. So, it's gonna change and it's gonna go upward right, because we are forming more of the product. Then less of the reactants, so reactants go down. Because now there is two of them, so they will go down this way (explaining as she draws the graph). Do you understand? **Stds:** Yes	**Overview:** Demonstrating the effect of increasing pressure on chemical equilibrium graphically while explaining why the reverse reaction will be favored.; emphasizing on the importance on one being able to demonstrate the effect on a graph. **Qualitative in-depth analysis:** In this segment, students are asked to draw a graph on pressure change for a reaction displayed prior in the discussion (LPK). Students, however, demonstrate a confusion as they failed to draw the correct graph after a disturbance. To explain this, Noma reminded students that before any disturbance, the reaction was at a state of chemical equilibrium with all reagents having constant concentrations. This is an aspect of curriculum saliency (CS) as it highlights to students the focus point where the change of concentrations of reagents should start. She then explained as she drew the graph (R) why the concentration of products increases whilst that of reactants would decrease. Three components are evidently interacting in this episode with LPK linearly linked to three components that are interconnected. The episode in displayed on the TSPCK map below. **A sophisticated TSPCK episode: LPK-CS/R** 
<u>Emphasis on the effect of a disturbance on chemical equilibrium; the changes on the concentration time graph:</u> 97-101mins	**Overview:** Provides a summary on factors that affect chemical equilibrium. Displays an arbitrary concentration time graph with two positions of chemical equilibrium

Noma: So, the key thing is having an ability to express your reaction to the graph. So, at some point something reacts neh. So, this was our normal, our initial equilibrium (draws the concentration versus time graph). It means that the production of the product and the reactants is at the same rate. But there is something extra now that is disturbing it. At times you find that either your reactants or your products, at times you find that you are gonna form more of your reactants, so your reactants will increase, and your products will decrease, or it can be the other way around, depending on whether what temperature does, or pressure does, or concentration does to the system. The most important thing is the reaction will always want to reduce the disturbance added and later the new chemical equilibrium position will be reached. So, you should be able to present all these graphically (presents a new equilibrium on the graph).	and then notes that when a reaction is at equilibrium, someone can decide to introduce a disturbance, which will the effect on the state of equilibrium, forcing the system to react in such a way that the reaction that opposes or reduces the disturbance is favored. **Qualitative in-depth analysis:** This segment summarizes on factors affecting chemical equilibrium. Using a concentration time graph (R), Noma explains how a reaction that has reached chemical equilibrium can respond to a disturbance in relation to the Le Chatelier's principle; by always acting in a way that reduces the added disturbance (CS). Two components are evidently interacting in this episode as displayed in the TSPCK map below. **A Basic interweaving TSPCK episode: R/CS** 
<u>Re-visiting the dynamic nature of chemical equilibrium:</u> 101-105mins **Noma:** Did you understand the concept of dynamic equilibrium; did you understand that? **Stds:** Yes, ma'am **Noma:** There was an example that was made in the lectures, for example when the escalators are going up, and you decide when you are in the middle of the escalator that you are not supposed to be going up. Then you start to run down the same escalator. So, you start running backwards. So, the same rate that the escalator is going up, the same rate that you are running. So, somebody looking at you from the distance, seeing you, you are in the same position. Do you understand what I am saying? So just because for someone looking there is no change in position, it does not mean that there is no movement. The reason of no change in position is because both the escalator and the person are simultaneously moving at the same rate.	**Overview:** To emphasize on the dynamic nature of chemical equilibrium, Noma provided learners with an analogy of using escalators, moving in the opposite direction as the escalators. She indicated that because of this, the position of a person moving will not change which indicates equilibrium. She emphasized then that just because there is no observable change in position does not mean there is no movement. **Qualitative in-depth analysis:** Noma referred students back to the dynamic nature of chemical equilibrium and made an analogy of a person riding an escalator in the opposite direction in which it is moving (R). She then explained that just because at some point there is no change in position for the person moving does not necessarily imply that there is no movement (LPK), rather that that both the escalator and the person are simultaneously moving at the same rate, because they have reached a state of equilibrium (WD). Three components are interactively used in an interweaving fashion in this episode as displayed on the TSPCK map below. **A Proficient TSPCK episode: R/WD/LPK** 
<u>A general evaluation of the lesson:</u> 105-120mins **Noma:** Checking students' understanding further…so each one of you is going to tell the class what they learned today about chemical equilibrium… **One std:** I learned how to present an equation using the graph… **Noma:** Ok, next person… **Another std:** Ok I learnt that all endothermic, I mean the exothermic reactions, the particles react very quickly. When you increase the temperature on exothermic reactions, the equation… **Noma:** The equilibrium… **Same std:** Eh, the equilibrium favors the reactant side… **Noma:** Next… **Another std:** Ma'am today I learnt a lot about moles and matter. But my highlight in this lesson was on the open and closed system. The open system which means the gases interact with the environment, and the closed system which takes place in the closed environment. And you taught me about daily products which relate to the lesson, which is the microwave, which is the closed system, and I did not know of. And my other highlight was the exothermic which is when the particles, eh if the reaction taking place with the particles having more energy and endothermic which takes place, where the particles have less energy… **Noma:** Always talk about collision. Always, collision is the main thing because there is what we call the collision theory. So, when they look at the collision theory, they look at how many particles collide with each other at a certain time. They calculate	**Overview:** Noma asked students to present on what they have learned in the lessons. The presentations are general and not guided by any questions from Noma. **Qualitative in-depth analysis:** Acknowledges learners' responses to what they have learned without any expansion (LPK). **This is not an episode, as the segment only displays learner prior knowledge.**

that as well, the orientation and whether the particles have energy as well. So, collision theory is the main, main thing. **Same std:** And the other highlighted part was the chemical equilibrium which is affected by three factors, which are pressure, volume and temperature… **Noma:** Not volume… **Same std:** Concentration…yes **Noma:** Thank you…next **Another std:** Eh, I learnt that there is exothermic reaction, which is a reaction that collides very quickly and easily, and then an endothermic reaction collides really weakly and less. Um, I know that chemical equilibrium has three factors that affect it, which is temperature, concentration and pressure. And that in a pressure graph, if pressure is increased, then in the reactant side, then it goes to the endothermic side…yeah **Noma:** That is fine…always go back to the collision theory… **Another std:** Ok, what I learnt today, I learnt about the collision theory which deals with two reactions, the endothermic and exothermic. Exothermic is a reaction whereby the particles collide with one another rapidly and then the endothermic is the reaction whereby the particles have less energy…yeah that is about it… **Noma:** Yeah, you did not want to say anything neh? **Another Std:** Ok what I learnt was the Le Chatelier's principle which focuses on chemical equilibrium and the three factors that affect it which are temperature, pressure and concentration. And that basically helped me in drawing the graphs because it made me think about how particles collide with one another. Then that made it easier for me to draw the graphs… **Noma:** Ok, thank you…next **Another std:** Ok, I learnt about collision theory. It depends on the number of particles per unit time that collide. And it depends on the concentration of the particles, and then on the… **Noma:** So, for the reaction to take place, there has to be collision between the particles. **Same std: …**and then for an exothermic and endothermic reactions, exothermic reaction is a reaction in which energy is needed, they need the kinetic energy, and the collisions of the material are… **Noma:** Exothermic? **Same std**: yes **Noma:** Ok, thank you **Same std:** And then endothermic is where collisions react… **Noma:** Can I ask you a question? With an endothermic or exothermic reaction, which one would you prefer adding a catalyst to it? **Same std:** The endothermic **Noma:** Thank you guys, I can see that we have learned something	

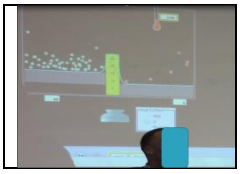
Appendix S: A detailed analysis of Lerato's lesson

Episode Extract	Qualitative in-depth analysis
<u>Introducing collision theory:</u> 0-2mins Lerato: Alright...so today we are gonna be talking about chemical equilibrium right.... you will see that this is just a matter of, you know, thinking about things very differently, you know, from what you have learned before. Or using those very same things that you have learned to sort of explain certain things that are happening, particularly with chemical reactions. So, this is basically chemical reactions. All that we are interested in here is further understanding on how chemical reactions happen. Things like that. Okay, so do you guys know about collision theory? Stds: No, some; yes Lerato: You have seen this word before, right? So, who can tell me something about the collision theory? Stds: Silence Lerato: So, collision theory is the theory used to explain how chemical reactions happen. How come that when we put staff in a beaker, all of a sudden there are other things that are made, you know. What happens, you know? And that is the fundamental purpose of science; to understand what happens. So, all we are asking ourselves is why? So, we are gonna just have this explanation and then we should know how reactions happen.	**Overview:** Begins by highlighting that all reactions obey what is referred to as collision theory; and explained that the theory explains how reactions happen. **Qualitative in-depth analysis:** Lerato introduces students to collision theory, the theory used to explain how reactions happen (CS). This is the only component in this segment; hence this is **not a TSPCK episode.**
<u>Episode 1</u> **<u>A simulation of how reactions happen:</u> 2-7mins**  Lerato: Ok, so we first start with an empty vessel right (displaying a slide on the board with a diagram that indicates an empty vessel. We want to see what really happens between those two things that we put so that they give us whatever we are looking for? So, we are going to start right, and put a few things in there (using a pump on the side to pump in reactants). So, say we put a certain amount of, let us say we put ten of A, ok. It could be ten moles; it could be 10 particles in particular because it is actual particles that it is showing us. Eh, so we are gonna put in also another reactant right, which is this (as he puts in another reactant and is being displayed/demonstrated on the slide. So obviously, normally when we put in staff, I think from grade nine, we learnt that particles, um, they move. They are in constant motion. They constantly move. So, when we put two things, we know that these things, they are gonna move, right. But that means that there is not only one thing that is inside. There is something else that is available that these things can move against, they can move past, they can bump into, right? And the whole reason why bonds rearrange is because of the fact that something hits something in the right way that something happens. There is something happening right. So, what is important is that, when you put staff inside, things bump into each other and those things that bump into each other, (particles in a simulation start moving) ... Ok so as you can see, things start to move around within the vessel right. And when things start to move around, they start to bump into each other. So, we put in yellow and purple bubbles...but we have something else, different forming (referring students to the symbolic chemical reaction at the bottom of the simulation). So, as we can see, when things hit each other at the right way, bonds rearrange (pointing both to the reaction and those in the simulation reaction vessel). They both rearrange as these things hit one another.	**Overview:** Demonstration using a simulation of how reactions happen; explaining how when reactant particles hit at a right orientation, bonds break and rearrange to form new bonds, thus resulting to formation of something completely different from what was originally added into the system. **Qualitative in-depth analysis:** Lerato began by displaying a slide that presented a video simulation on how a reaction happens (R). He then reminded students that particles are always in constant motion which they have learned from their earlier grade which then becomes a pre-concept that helps them to understand collision theory; an aspect of curriculum saliency (CS). He emphasized that because particles are always moving, when they bump into each other at the right orientation, they begin to rearrange to form something else (WD) and this rearrangement is observed as the video is played. The episode has three components that are evidently interacting as displayed in the TSPCK map below. **A proficient interwoven TSPCK episode: R/CS/WD** 
<u>2. Conditions for a chemical reaction to occur:</u> 7-10mins Lerato: But what is important is that not all the collisions that are in there, result in formation a new thing. But what is important is that those collisions, they have to have two things that are very important. 1, their collisions must happen in the right orientation. So, for example, if this thing naturally bonds will break easily if it gets hit here than here (referring to the bond between particles in a molecule). Obviously if it hits here (on an individual atom within a molecule), there will not be any bond breaking right, unless when it hits there in the middle. So, if, all the collisions that are happening, all of them are not going to be successful or effective right, they are not going to create bonds or create what we want to see right. Secondly, if for example right; that thing about kicking a ball...if you want to score a ball over there and you kick a ball, if your shot is not strong enough, you will not score a goal right. This means if these things bump into each other at a relatively slower rate, with not enough energy, they are unlikely to form new bonds. So, they need to hit with just the right amount of energy. And if you find two particles that hit each other at the right amount of energy, new bonds will form.	**Overview:** Provides the conditions necessary for a reaction to occur; collision at a right orientation, colliding with the right amount of energy. Used a symbolic molecule and an example of one trying to score a goal as an example to emphasize on the conditions. **Qualitative in-depth analysis:** Lerato began this segment by emphasizing on what conditions are necessary for a reaction to effectively take place and result in formation of a new thing; collisions happening at a right orientation and bumping into each other with enough energy. This is an aspect of what is important, which is curriculum saliency (CS). He demonstrated this using one molecule that was displayed on the simulation to emphasize on the right angle in which the reactants should hit each other and an analogy of someone attempting to score a goal to represent the right amount of energy needed (R). Two components of TSPCK are evidently used in this episode as displayed on the TSPCK map below. **A basic interwoven TSPCK episode: CS/R**



1. <u>The activation energy:</u> 10-15mins

Lerato: This energy that is needed for effective collisions to happen and create new bonds is what we call activation energy. It is the minimum amount of energy that is needed for those collisions to happen and give you a product. And every single reaction has a minimum energy required. So that energy is very important in terms of a reaction. But what is important is there is a specific amount of energy that every single reaction must overcome within its collisions to be able to convert itself off to products right, or for the reactants to convert to products as you can see in the video over there. If the energy is not enough, collisions will not be effective and so products will not form. As you can see in the video, not all particles that hit each other result in formation of products. And that is why in most instances right, you will not get all the reactants forming into products. Why do you think that is the case? From what we just spoke about, why wouldn't everything convert into products?



One std: Collisions do not happen effectively
Lerato: yes, because collisions do not happen in the right way. So, the right collision, the right angles that are suitable for that reaction could not occur. So, which means obviously, there would be some that are still in there right. And we know because as time goes, there will be more and more products forming. So, which means it is going to be harder for particles of the reactants to bump into each other, because they still have to now go around eh, products before they can actually hit each other. So as the reaction continues, that is why you will see that eh, you do not keep forming products. So, which means every single reaction doesn't happen to completion right. So, which means a reaction doesn't fully...like we write it here, (referring to the equation on the slide; A + B ↔ C) and that is why we are gonna talk about this later. That is why it is important that you do not imply that your reaction continues to the end. That all of these reactants will convert to all of these products right. Which is how we, you begin learning chemical equations like that because there are a few that behave like that. But as we move forward, which is what we are going to do today, we are going to learn what it means for a reaction to, not necessarily stop, 1 and 2, not all the things that are put inside have converted into the things that we wanted right.

Overview:

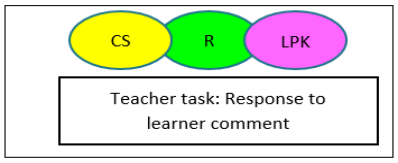
As an expansion to the previous episode, Lerato explains that the minimum amount of energy needed for each reaction to occur is referred to as activation energy which is displayed on the video played. Emphasis on the importance of this energy is made that without that required energy; there will be ineffective collisions which will not result in formation of products.

Qualitative in-depth analysis:

Lerato begins the segment by indicating to students that the minimum energy that each reaction needs to result in effective collisions and form products is referred to as activation energy (CS). He then pointed out on the video (R) that particles that do not have enough energy (even though they still bump into each other), do not end up forming products. This he did to explain the fact that most reactions do not really go to completion like students might have learned before (LPK).

Three TSPCK components are evidently used interactively in this episode as displayed in the TSPCK map below.

A proficient interwoven TSPCK episode: CS/R/LPK



4. <u>Open and closed systems:</u> 15-21mins

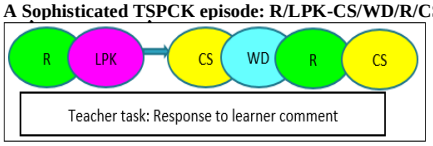
Lerato: Ok, maybe we should start here. So, I want you guys to work in your pairs, right? I want you guys to talk about, to discuss two things right. What happens and what is the difference between you boiling water when there is a lit, and you boiling water when there is no lit? So, you put a pot on the stove, you pour water, then you boil it, you do not put a lid on top. Then the second situation, you put a lid on top and let us assume that the lit is airtight. It does not do funny things. so, you even extra seal it, you extra seal. So, discuss amongst yourselves for five minutes as I prepare this then we will talk. ... Right, we are back, so what did you guys at the back discuss?
One std: Ok, eh, when there is no lit eh...
Lerato: When there is no lit?
Same std: Yes. When there is no lit, we lose water...
Lerato: We lose water, right?
Same std: The water will evaporate
Lerato: yes... (writes it on the board)
Same std: Eh, when there is a lit, it will not evaporate...
Lerato: If there is a lit?
Same std: yes
Lerato: If we have a system that is open, what happens?
One std: We lose
Lerato: We will lose right? So, in general chemistry language we say we lose mass, right? So, we are gonna loose of whatever we have in there right. If it is a gas, then obviously it is gonna escape through evaporation, right? So, we know, in an open system, we are gonna lose staff. This means we can never really achieve that whole converting back that he was talking about. Which is very important to the concept of chemical equilibrium? Secondly, in a closed system, we are not losing anything right. So, which means, you keep getting this whole process of your staff are turning back into other staff, and then staff is turning back to other staff right? This is actually very powerful because it means if you think about it, if we are in a closed system our reaction never really stops. It never stops. Even if looks like it stopped, it does not stop. Which is quite interesting because you know, generally you will see a beaker and say, ah no, that thing was blue, now it is pink. So, it stopped this thing right. But remember we are talking about particles here. Particles are super small, very small. So, you can't even say, ah, no three of them here, we have got 10 there...you know. And that is what is important. It is that, because that happens at a microscopic level, you can't see that observable change. You can't see that it is happening, but it is happening right? Because we know that in a closed system, right, that there is this continuous rearrangement back and forth with reactants forming products and products back to reactants. It is however relevant to note that when we are dealing with water, water is not actually, there is no chemical reaction when dealing with

Overview:
The segment introduces conditions for chemical equilibrium; closed systems as opposed to open systems and the reversibility of reactions. This is done from a scenario of water in an open and a closed pot, providing characteristics of each system, where a closed system enables for reversibility of a reaction. Emphasis is then made that although a physical process of water changing phase is used, this is not necessarily a reaction, but that there are reactions that actually reverse.

Qualitative in-depth analysis:
The segment begins with a scenario of boiling water in a closed versus an open pot (R), which learners are to discuss in their groups and give feedback (LPK). Lerato goes on to introduce learners to the types of systems open and closed, and their characteristics in terms of loss of mass by open systems, and the opposite for closed systems (CS). Further emphasis by Lerato pointed out the continuous nature of reactions in the closed systems that never end, where reactants rearrange forming products, whilst at the same time products react back into reactants (WD). His explanation also highlighted that the reversible nature of the reactions can only be seen at a microscopic level (R). The discussion ends with an emphasis that the change of phase of water is not a chemical but a physical which was used to explain the concept under discussion. This emphasis brought though a different aspect of CS focusing learners on what is important to conceptualize.

Four components are interactively linked in this episode as displayed on the TSPCK map below.

A Sophisticated TSPCK episode: R/LPK-CS/WD/R/CS



water. Water is still water. It is just water in another phase. You know this, it is still water. When we look at closely, specifically other chemical reactions that are actually having a chemical reaction right. So, this is not a chemical reaction. It is just a physical reaction. But it is important that we use it to sort of understand and get our heads around what exactly happens in a closed system and sort of have a basic idea of what happens in an open system.

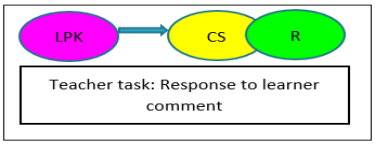
Evaluation of learner understanding on types of systems: 21-27mins

Lerato: Can someone tell me what we said happens in a closed system vs. in an open system? What happens in an open system? This means we did not close it, there is no sealing…
One std: particles are exposed to the surrounding air…
Lerato: T: yes... not necessarily because, if we talk about particles, they are very, very small. So, if we talk about air, air in itself is a particle. So that is something we need to talk about when we rationalize this thing. Air is also a particle. So, what happens here so that there is more space available, not that it moves to another air. It is just that there is more space available because the volume is not fixed (demonstrating with his hands). We do not have a fixed volume, so it has more space to move around. So, the volume is no longer just the beaker that you are working in or whatever that you are working in. It is also the beaker plus this whole space and that is why you lose staff because particles are always moving, remember that? It is not that they are standing still. So even there, they are sort of going like this, going like that (demonstrating with his hands). Some are bumping into each other, some are leaving, some are coming back in, which is very important in understanding what actually happens from a reversibility point of view. So, we looked at that (showing a slide on boiling water from an open and a closed pot), right, and we said that mass and energy is lost which is the energy that is very important now but is also part of what happens in an open system. And then in a closed system there is no mass lost. There is also energy lost, but that is not important right now. So now question. What kind of system is this (showing a slide with a pot that is partly closed)?
One std: Open
Lerato: It is open right? So, what is important to understand about an open system is that there is no space, no small space, particularly fixing the volume. So even if we have a small hole like this, which means this volume is not, whatever they say a pot is when they write...they can say a pot is 10ml whatever the case maybe. So, which means this volume is not fixed. You have exposed this, which means this whole part (referring to the area outside the pot), this whole part, is part of your volume. So, this is an open system, right? And this is why you will still lose water right?

Overview:
Asking learners to explain the difference between an open and a closed system to check if they have understood from what they just learned. He then pointed out that with open systems; the space for reactions to take place is not confined to a specified volume as the reaction is exposed to the surroundings outside the actual container/reaction system.

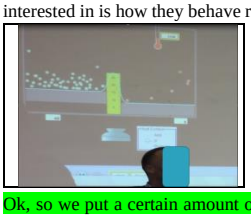
Qualitative in-depth analysis:
The teaching segment begins with a question requesting for learner pre-requisite knowledge (LPK). Lerato's response to the learner comment starts with showing that open systems do not have fixed volumes and the reactants and products can easily escape to the surroundings outside the reaction system whilst the opposite is true for closed systems which have a fixed volume that prohibits the reactant system to its surroundings, (CS), using an open and a closed pot diagrams as representations (R).

An interactive use of three components in an explanation given by Lerato is presented in the TSPCK map that follows.
A Proficient TSPCK episode: LPK-CS/R



Reversible reactions and their conditions: 27-32mins

Lerato: But yeah, we talked about reversible reactions, right? So, what are reversible reactions? First, we said it already; it has to be in a closed system. Otherwise, it will not reverse. Because as soon as things form, they leave right. Some will stay, but some will leave. So, and even some of the products will leave. So, which means they are sort of getting in the way of things rearranging and going back to the products right. So that is the first things. First, condition is the reversible reaction has to be in a closed system. 2. What we are interested in is how they behave right. So, I am gonna jump to another illustration that speaks to this.

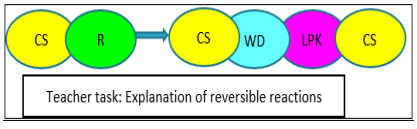


So, these are your products (referring to the left side of the illustration), this is the reactants (the right side). And I want you to think of it as an actual chemical reaction. So, we are going to put it like this, writes on the board (green)... so green will represent a certain reactant or reactants that are put into the system and then giving products right. So, this will be A, and this will be B, right? Ok, so we put a certain amount of A (begins the demonstration, adding A-reactants into the system) right. So, they have to give us B, right? But this is showing you the minimum amount that it requires for it to be converted... So, the way they show it is a bit shaky, but it plays the course right. So, when these things jump, you will see that they jump to the other side. You see, they begin to jump. And remember, this also speaks to the concept of concentration on your reaction. The more you put staff, the more that staff is likely to collide. The more staff are likely to collide, the more products, the more likely you are gonna make products right. It makes sense.
Stds: Yes
Lerato: Cool, so now we have products. So, you see now, as time goes, there is going to be more products. But they also collide themselves. So, it's not like when they form, they stand still in the reaction vessel. And they also remember will collide also, and they might rearrange right. Converting back to reactants, right? The products do not wait for all reactants to react and form products. As long as their number increases and they begin to collide, they react to form reactants back. And because this reaction is specific right, so there is a particular energy that they would need to go back (referring to the activation energy for products to react), and it's higher than the one needed to go forward. And that is what happens when we have chemical reactions. Like, it looks like it is going in a particular direction right. But it can also go backwards. If you take care of the conditions or the fact that it is a closed system, then you can get a special case where actually chemical reactions are going like this right (demonstrating a back-and-forth movement with his hands). But remember that, like I said, because the energy that it requires for them to react back into reactants, then you are gonna find a situation whereby you will not get a lot of reactants, a lot of products going into reactants vs a lot of reactants going into products, right?

Overview:
Refers students back to reversible reactions and emphasizes that they can only happen in closed systems. He then plays a video displaying a reversible reaction and indicates to students as they watch the video that the reverse reaction (products forming the reactants) does not wait for all reactants to form products before they react back to form reactants. Rather, immediately when they gain enough activation energy, they begin to react and form reactants; hence the reaction does not end.

Qualitative in-depth analysis:
With reference to reversible reactions discussed in previous segments, Lerato emphasizes on the important condition for reversibility to take place; closed systems (CS). This introduction is followed by a video demonstrating a reversible reaction at a microscopic level (R). In this instant, Lerato also emphasized on the effect of concentration on the number of effective collisions, which is an aspect of curriculum saliency (CS). The reversible nature of reactions is a concept that students find difficult (WD). He puts more emphasis on the fact that a reverse reaction starts before all reactants are used up, which is a common learner misconception (LPK). Lerato specifically highlighted that as soon as the products have absorbed the necessary energy (activation energy) they will start to react and form reactants. This is an emphasis of an important concept that helps students understand how reactions happen, a pre-concept for understanding chemical equilibrium reactions (CS).

Four different TSPCK components are evidently interacting, and one repeating as displayed in the TSPCK map below.
A Sophisticated TSPCK episode: CS/R-CS/WD/LPK/CS

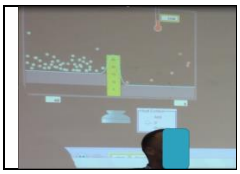


A simulation emphasizing on reversibility: 32-37mins

Lerato: (Referring back to the simulation) …so those things that we are putting in, we then say that they are the reactants, and that reaction is what we call the forward reaction. And

Overview:
Use of a simulation to explain the reversible nature of chemical reactions, with great emphasis on effective collisions needed for reactions to occur which are affected by the amount of energy the

obviously, because this is a reversible reaction, it actually has a reverse reaction. And a reverse reaction is when the products are forming back into reactants that we had in the beginning. So, as you can see, you will see (slide Demonstration/simulation).

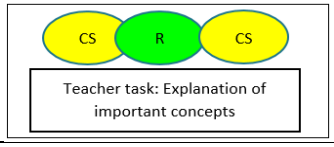


Ok so you can see from the visual demonstration that not all of them actually move in the same speed. So that's what I was talking about. Things collide with one another. It is going collide with the side of the container. It collides with the side of the container, and then it's gonna collide with another particle, and then it moves in another direction and that is what affects the speed within it right. And we are gonna do something just on the side note. Eh, my point is this, you see that guy (referring to one of the product particles), that guy is turning back into reactants. And you can see, the reaction frequency of the forward reaction happening is higher than the backward reaction happening, which is very small, because this product must start from here, (pointing at the bottom of the reaction vessel) going all the way there to overcome the high activation energy. So, they need to real have sufficient energy for them to be able to collide, on top of having to collide in a what? What did we talk about considering as important in collision theory? Orientation right, we talked about orientation. So, on top of them having to worry about you know bumping into one another in the right way, they also have to worry about that energy (referring to the activation energy). Now it is important also to see that this container is not open right. If it was open, then we were in trouble. Why?
One std: Things will be lost

reagents need to react, and collisions happening at a right speed and orientation.

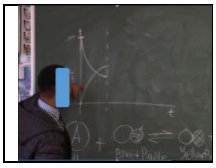
Qualitative in-depth analysis:
On explaining the simulation that demonstrates reversibility of reactions; Lerato started by highlighting which reaction is referred to a forward, and which one is the reverse reaction, as aspect of curriculum saliency (CS). He then pointed out as reflected on the simulation (R), that not all collisions result in a reaction happening, as the speed and orientation at which they collide, and the right amount of energy are important for effective collisions (CS).

The episode shows an interaction between two different TSPCK components, with two other components repeating. The component interactions are displayed in the episode below.
A basic interwoven TSPCK episode: CS/R/CS



<u>The concentration versus time graph:</u> 37-41mins

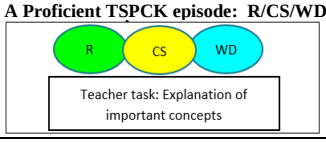
Lerato: Now let me show you how we can represent this reaction in a graph, a concentration versus time graph. So, reactants start of at a higher concentration (as he draws the graph) and less of them collide with time.
Products, there was none (pointing at the first position of products on the graph), then they start forming. Some of them are converting back to our reactants. Because we know they collide also, and they go backwards. So, which means, this graph is only valid for two things right: for a closed system and what else?
Stds: Silence
Lerato: What type of a reaction is this?
Stds: forward...reversible
Lerato: Thank you, (writes reversible on the board). But as the reaction continues, we know they will not go on forever right. We will not have a continuing increase in products and decrease in products. It cannot do that right, given what we know. That whole process, it's also showing us that thing that we already talked about that it is dynamic. If you do not see something in your reaction, there is still this whole that's happening. So, which means it is a continuous thing that is happening.



Overview:
Using the video as reference point, the teacher draws a concentration versus time graph on the board and explains to students that the concentration of reactants is higher at the beginning of the reaction and decrease with time, whilst the opposite is true for the concentrations of products. The dynamic nature of the reaction is also highlighted.

Qualitative in-depth analysis:
By pointing students back to what they observed from the video played on reversibility of chemical reactions, the teacher draws a concentration versus time graph (R) which is further explained in terms of how the concentrations of reactants and products change with time (CS). Lerato made explicit that the graph is only valid for reversible reactions happening in closed systems, and the dynamic nature of the reactions which are continuously happening (WD). This implies that reversible reactions do not come to an end.

Three different components are evidently interacting in this episode as displayed on this TSPCK map.
A Proficient TSPCK episode: R/CS/WD



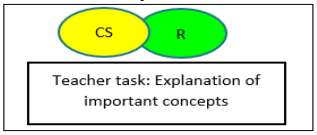
<u>Changes in the rate of forward and reverse reaction:</u> 41-43mins

Lerato: But we already also know that this thing, at first right, here (at the beginning of the graph), the rate at which this thing (products) was being produced, was more than this (reactants) right? Ok let me explain right... It is for all the chemical reactions right; the rate of the chemical reaction is how fast products are produced, or how fast the reactants are used up right? So, we are going to assume that we are looking at a part where the reactants are being consumed or only the part where the products are being produced right. Does that make sense?
Stds: yes
Lerato: Right... So, we are interested in the speed basically of the reaction. We are interested in how fast this reaction is happening. Going that way or that way (towards the product or reactant side). So, we said first that because this is what we are interested in; we called it the forward reaction. We have the rate right, of the forward reaction...and then we have got the rate of the reverse right. So, we had the speed at which products are forming back into the reactants. And if we see here, (back to the graph) we see here that (at the beginning of the two graphs) the production of this is very high (products). And then it gets to a point where it starts slowing down, slowing down...

Overview:
The rates of forward and reverse reactions are explained using the concentration time graph.

Qualitative in-depth analysis
Lerato begins this segment by explaining what rate is and continues by explaining how the forward reaction started off at a higher rate and decreased with time (CS) as demonstrated on the graph (R).

Two components are evidently interacting as displayed on the TSPCK map below.
A basic TSPCK episode: CS/R



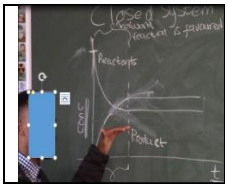
<u>Further emphasis on concentration versus time graph:</u> 43-50mins

One std: So, sir, the concentration of products goes back down after some,time right in that graph?
Lerato: laughing...remember right, we have our special conditions right. So, if you are saying what goes up must go down, you would imply that this thing (activation energy on the video simulation) is not valid right. Remember that your products will need a different energy to go backward right. So, if it needs a different energy, it means there is never a point where these things (products) are going to be in such a position where they are going to strongly go backwards and produce all of the reactants back. Do you understand (referring to the simulation-collision theory)? You see that this is increasing, and it is decreasing (referring to products and reactants respectively). So here, the rate of the forward reaction is decreasing,

Overview:
Explaining a concentration versus time graph; emphasis on how concentrations of reactants and products change before equilibrium is reached, and what happens to the concentrations when equilibrium is attained
He denotes on the concentration time graph the positions displaying Rf>Rr, Rf<Rr and Rf=Rr, where Rf refers to rate of forward reaction and Rr refers to rate of the reverse reaction. Further emphasis is made that a point where concentrations are constant is referred to as chemical equilibrium which also implies that the rates are equal.

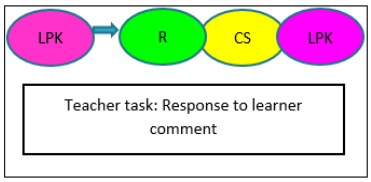
Qualitative in-depth analysis:

and the re reaction is increasing. Then until you get to a point where you the graph not changing (referring to the equilibrium state). So, what do you think is happening there?
one std: the rates are the same
Lerato: Eh, not exactly, not exactly...what graph is this?
Stds: Concentration vs time
Lerato: Yes, concentration vs time right. **So it means here that the concentrations remain the same, they do not change.** It does not say anything about the rates, right? From the information that it is telling us about the concentrations, we can say something about the rate. But the graph itself is not saying anything about the rate because when we write this, we are looking at the concentrations of what is inside our vessel right. Does that make sense?
Stds: No
Lerato: Concentration vs time, not the rate vs time, right
Stds: ooooh...
Lerato: So, you cannot say that the rates are the same right? You cannot say rates are the same. **You can say that the concentrations at that point remain the same.** But you cannot say rates are the same ok? So there arrives a point (draws) where the concentrations actually stay pretty much the same, right. If we look at it from a microscopic level, eh the particles are still colliding with one another, effectively when we take the mean of all the particles that are available, over time, they sort of remain the same right. If you remember when we were at 34, then we came to 35, then 36, then it becomes a 25, it becomes a 24, then it becomes a 25...so effectively they sort of, the concentrations stay the same after a, at a certain point right. So, which means the ability of a reaction at chemical equilibrium to behave the way it behaves is because of those two things. 1. Products keep forming into reactants and reactants keep forming into products. But they have to form at the same rates. Otherwise, we would favor a certain reaction. Do you understand? For example, when we say favor here, it means the rate of forward was definitely greater than the rate of the reverse (writes on the part before equilibrium: rf>rR). Because the things that are being produced that way (forward) are much, much faster than the ones that are being produced this way (backward), right. So conversely it is the same. If something happens after the reaction, which is something we are gonna talk about after we come back from the break, that there is also something that you can do to this system that is here (referring to a point in the graph after equilibrium is reached) that will have a different effect that maybe we change this thing, right (referring to rf>rR). But we will talk about it later. For now, we are just talking about this one (equilibrium position on the graph). And this is basically what chemical reaction is. Chemical equilibrium I mean (denotes it on the graph). So chemical equilibrium is a point where the rate of the forward is equal to the rate of the reverse (denotes on the graph; rf=rR).



This segment is initiated by the learner question (LPK). To address this, Lerato uses the simulation (R) to explain how the activation energy affects the rate of reactions (CS). He further explains by showing that with time, the concentrations of the reagents remain constant as the rate at which reactants form products equal to the rate at which products form reactants. The issue on nature of concentrations of reagents is a misconception for most learners (LPK).
This episode displays five components evidently interacting in a teaching segment as portrayed in the TSPCK map below.

A Sophisticated TSPCK episode with both linear and interweaving components:
LPK-R/CS/LPK



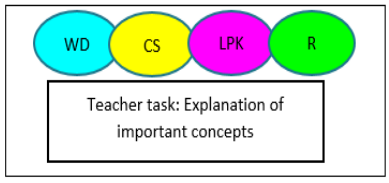
Emphasis on characteristics of dynamic chemical equilibrium: 50-55mins

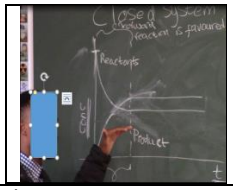
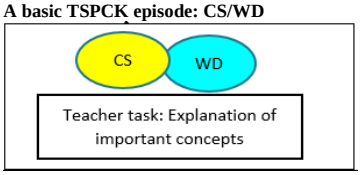
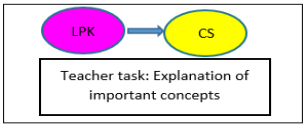
Lerato: So now we know why we actually say that the rate of the forward is equal to the rate of the reverse right reaction at equilibrium. We get that from what we know about what happens in chemical reactions right. We know what happens, how collisions happen. All those considerations, they bring us to this point that when two of these things, because of the reversibility, fall back into this. But what is important is the rate which talks about the amount of concentration which is produced at a specific time. So, when we take eh, how much of products are forming into reds, eh there are the same amounts those reds forming into greens at equilibrium. So, it's a special moment, a special time in the life of a chemical reaction, because we know that it is gonna go pretty much forever unless you change the system. If you open it, then its gonna effectively change what is happening to the system. But if we keep everything the same, then we expect that if this were me, when I was 23 years old, when I am a million years old, the same reaction would still be doing the same thing. And that is a beautiful part about reactions... Actually, you can finish school and get married if you wonna get married of cause. You can do whatever. You can have children, and still come back and still check. The concentration of reactants vs the concentration of your products, and they should because it works like that, it should give you the same average... It does not make sense, right?
Stds: Yes
Lerato: You expect that after some time things must go down. You expect that there must be something, something must happen. You cannot just have something continuing like this. But if you keep everything the same, you do not change anything right. And that is the beauty of chemical equilibrium. So, then I have a brief discussion after this right. So, I hope you took all these things down. So chemical equilibrium is but a moment of a chemical reaction that we look at. We look at a particular time and we say ok, here, what is happening here? And we have been able to at least have some idea of what happens at chemical equilibrium. A concentration stays constant of products, and the concentration of reactants stay constant right. So, they don't change right. Effectively they don't change right. And our rates, the rate of the forward, which means reactants going to products, happens at the same rates as products forming back the reactants. This is why we call this dynamic equilibrium. So, this is a moment in time. So, when they ask you a test, they are maybe going to ask you about, a system is at equilibrium, what do you do to it? Do you understand? So, you look at it now right. You know certain things about it now. You know that the rate of the forward and the reverse is the same. You know that the concentrations stay constant right?

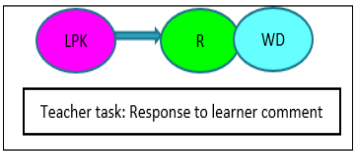
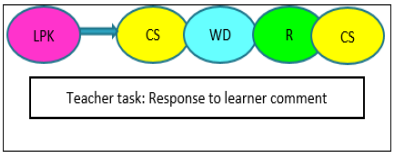
Overview:
Characteristics of chemical equilibrium are emphasized. This includes the equal rate of forward and reverse reactions as well as the constant concentrations of reactants and products, which are repeated multiple times in the episode. He continued to show that as long as all conditions are not changed, the reaction's equilibrium position will not change

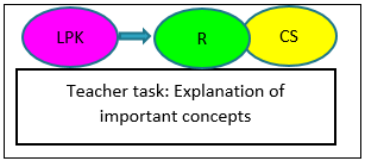
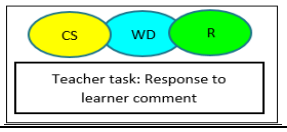
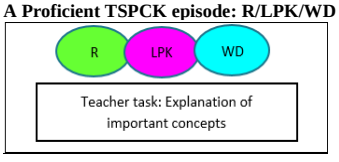
Qualitative in-depth analysis:
In this segment, Lerato emphasized on rates of forward and reverse reactions being equal at chemical equilibrium (WD) as well as the constant nature of concentrations of reagents, where the reactions happen continuously as long as the conditions of the system are not changed (CS). The two characteristics are repeated as a way of emphasis because they tend to cause learner misconceptions (LPK). Lerato then points students to the graph explaining that using their understanding of what happens at chemical equilibrium with respect to concentrations and rates they should be able to produce the necessary graphs (R), the concentration and rate versus time graphs.

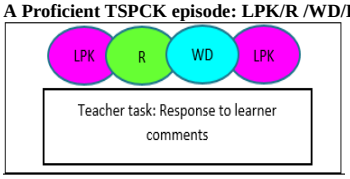
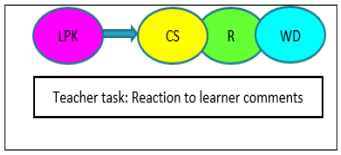
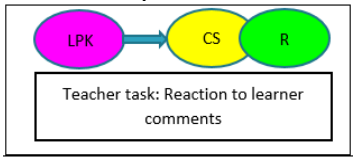
Four components are interactively used in this teaching segment as displayed in the TSPCK map below.
A Sophisticated TSPCK episode: WD/CS/LPK/R

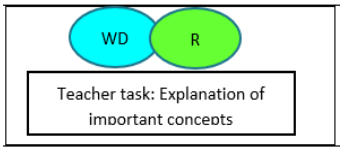
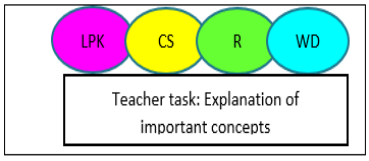


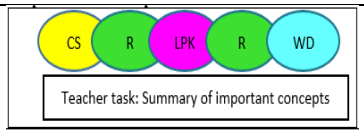
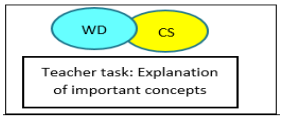
And you should be able to reproduce this graph right. For this portion and for this portion (products and reactants) because you know what happens before it gets here (at equilibrium) right. And typically, you find that maybe it has two reactants or has two products. But it is effectively this graph right. You know how to rationalize it, because you know, you know collision theory now. You know what happens in collision theory. What affects the collisions and how things form, why they form and why they do not form? And why they do not continue to form right? But now, before we got there, we had to do certain things to our reaction mixture. 	
A summary on conditions for chemical equilibrium: 55-60mins **Lerato:** So, the conditions that we had to consider for chemical equilibrium to occur were We had to ensure that our container was closed, and that the reaction was reversible right. That is what we were able to do, for us to arrive at this point. Eh, we had to ensure that the temperature there is constant, which is a very important thing. And eh, I think you should note that. So, we needed to keep our temperature constant, because remember, at no point did we heat, did we add ice, did we do anything to our reaction. So, which means effectively, our temperature stays constant for us to be able to get to this point. So, which means in the before right, there has to be a specific temperature (puts a slide on this) that we are saying ok, we are doing it at 35 degrees, and we are gonna move in that direction right. 2. The pressure effectively was the same. We never did anything to our volume, we kept it fixed. And we never heated which also affects the pressure. So, we did not do anything to those things. So, which means before we had a particular pressure, we had a particular temperature. And we put specific amounts right, of reactants that we put in our reactant vessel. So, which means also our concentration was important in the before. So, we put a certain amount. We put this amount and this amount. And they reacted together to give a specific amount. if you change those amounts, it means we will have a different chemical equilibrium. Because remember this corresponds to specific values. So, which means our, our, effectively our conditions in the beginning were not changed? Then we arrive to our special moment right. We have already talked about it. We know sort of what happens there. But now also, there are certain things that can happen afterwards right. So, what happens when we add something after we have arrived at chemical equilibrium? Obviously, we cannot continue the way we were continuing. When we come back after a thousand years, things ought to have changed right... So, when you change temperature, when you change concentrations, and when you change pressure, you affect the state of chemical equilibrium. And it has to; now, now think about it like this. Now you are starting from a different starting point. Unlike before when you did not have products, now you have products. And certain things are going to happen if either you increase the products in a reaction vessel or you increase the reactants that are in a reactant vessel. Things have to happen. Because we know from collision theory, if you add concentration, you are increasing the possibility of collisions. So, there should be the change in the rate of either one of these two, right? And secondly, if you increase temperature, there should be a change because the movement of particles is affected, and they will move much faster right. Thirdly, if you change your pressure, also that affects eh, the collisions because for example, if you change the volume, now particles have less space to move around and they are more likely to collide with one another. So, we will talk about it after the break. Then speak about what really happens after we have arrived after this special moment in a chemical reaction right.	**Overview:** Provides a summary on the conditions necessary for a chemical equilibrium to be attained which are a closed system, a reversible reaction, constant temperature and pressure and concentrations of reactants that started the reaction. He emphasizes this by reminding students of the simulation video that was played where all these conditions remained unchanged. He then argued further that unless those conditions are changed, chemical equilibrium is maintained, whilst the change in some factors such as temperature, pressure or concentrations of reagents can affect the state. **Qualitative in-depth analysis:** In this segment, Lerato summarizes on important conditions for chemical equilibrium including a closed system, a reversible reaction, and constant temperature, pressure and concentrations (CS). He also highlighted that the change in the three conditions; pressure, temperature and concentrations to a reaction at equilibrium would affect the state of equilibrium. Although there is no emphasis on how the equilibrium state will be affected at this stage, this is considered as a concept that learners find difficult (WD). Two components are interactively used in this episode and displayed in the TSPCK map below. **A basic TSPCK episode: CS/WD** 
Evaluation of lesson one: 60-64mins Lerato: Can someone tell me a story of chemical equilibrium. Take me through. If I did not know anything and you wanted to just tell me a story about chemical equilibrium. You know what we already talked about... She has a before, if you do not want to use a pronoun it, it has a now and it has an after. So, take me through the before. What happens before, and what we look for? What are the considerations that we explained? The things that we see and then after that we have chemical equilibrium? What do you know about that? One std: So, we have a sense that concentration plays an important part in equilibrium. And we had that we need constant temperature, constant pressure, and a closed container. And as reactants form products, products will also start to react to form reactants. And we will arrive to a time where the rate is the same for the forward reaction and the reverse reaction. Lerato: Yes... So, what do we call that? What do we call that special moment? Another std: Chemical equilibrium Lerato: Chemical equilibrium right. That is where stopped. Ok, it seems as you guys learned something today. And it is very important to understand because it has many applications right, which is a section that comes later on. But it is important to understand what is coming after this, which is how do we disturb chemical equilibrium, right. We are going to see some amazing things. We are gonna sort of; you know great situations that are suitable for us which is quiet the application side of this process. So, we are gonna first do an example for where we draw the concentration versus time graph. We know how to do it in general. So, we are just gonna do a particular reaction, and then we are gonna start to talk about what happens after that, from that particular equation right.	**Overview:** Review on what was discussed in the previous lesson; a summary by one of the students, followed by an introduction of lesson objectives. **Qualitative in-depth analysis:** The segment involves a review on the previous lesson where Lerato requested students to present their understanding of what they learned about chemical equilibrium thus far (LPK). Lerato only made an affirmation of the response given without any expansion and then provided students with an overview of the objectives of the current lesson. This is an aspect of curriculum saliency (CS). Two components of TSPCK are integrated in this segment as portrayed by the TSPCK episode below. **A basic linear TSPCK episode: LPK-CS** 
The rate versus time graph: 64-70mins **Lerato:** Ok we have said above that at equilibrium, the rates of reactions (forward and reverse) are equal. There is a graph that we can draw to demonstrate that even though we were able to tell that from the concentration time graph. We can demonstrate that using a rate versus time graph. Can someone remind us all what we said rate is? **One std:** Speed?	**Overview:** Presents a rate time graph on the board whilst noting that the rates change with time, with the forward reaction decreasing as the concentration of reactants in the system decreases whilst the reverse reaction rate increases with time. He also directed learners to a special moment in a chemical equilibrium where the rates are equal, depicted by a flat line on the rate time graph.

Another std: How fast reactants form products. **Lerato:** Yes, good. So how do you compare the forward and reverse reactions at the beginning? **One std:** Forward is faster **Lerato:** So, in graphical terms, this is what you mean (trying to represent the student response graphically by placing reactants up there within a graph). Why cannot we put it anywhere else (within the graph) Another std: Because reactants are more Lerato: Yes. But in certain situations, we do start somewhere here (after/at chemical equilibrium). We are going to talk about that later. We start somewhere here. Products somewhere here. But for now, we are starting at the beginning, beginning. So, what happens to the rate of the forward? One std: Forward? Lerato: Does it decrease like this? (Showing a constant decrease). Stds: No Lerato: So it decreases like this, right (draws a proper graph) ... What happens to, how does the reverse one work? Stds: It increase Lerato: (draws the graph that joins with that of reactants forming constant single line after some time) Another std: No (as the teacher joins the two to form a constant line at some point) ... Lerato: Why are you saying no; (labels the graph; rate vs time). Remember we have been saying that the rates are both equal at equilibrium. This is how their equal nature is demonstrated on the graph. Stds: Oooh!	**Qualitative in-depth analysis:** Lerato introduces the rate time graph by reviewing what they previously learned about what rate is (LPK). Lerato works with the students to draw the rate time graph (R) whilst explaining the changes in the rates across the graph, deliberately pointing students to the flat section of the graph where the two lines meet where the rates are equal; the position within the graph that portrays a reaction is now at chemical equilibrium (WD). The episode demonstrates an interaction between three TSPCK components as presented on the TSPCK map below. **A proficient TSPCK episode: LPK-R/WD** 
<u>The difference between rate and concentration time graphs:</u> 70-77mins **One std:** Sir why did you join those lines on the graph? **Lerato:** So, do not let the two graphs confuse you right. So, one does not touch, one touches right. So, it speaks to two things. 1. Rate is not the same as concentration. The rate is how the concentration changes over time. It is not the concentration itself, right. So, this is why in this graph here (concentration vs time), we were disagreeing with the fact that the rates are the same. Remember where someone said the rates are the same? And we said no, they are not right. And hence this whole region here (at equilibrium) agrees with that statement there. The rate of the forward reaction is the same as the rate of the reverse reaction, right. So, which means this part (equilibrium point on concentration vs time graph) is this part (where the two graphs meet in a rate vs time graph). It makes sense right because the other graph is on top of the other graph. So, this is the connection between the rates and concentration, and this is the graph that you will mostly see in the questions and in the textbooks right on rates. This talks to the rate, where this two connect (two graphs). So obviously, what is this part? **Stds:** equilibrium **Lerato:** Equilibrium right. And what do you say about equilibrium? Stds: the rates are equal Lerato: Right, the rate of forward equals the rate of the reverse. Graphically does it make sense? Stds: yes Lerato: Which means these graphs; they speak about the same thing. They are just showing different things. So, the concentration graph itself does not talk about rates but it tells you something about rates, right. This rate graph talks about the rates. No, it shows the rates and the relationships between the rates as the reaction proceeds. But it does not explicitly say anything about the concentrations. So you can't tell me what was the concentration here (the highest point as the reaction starts on a rate graph) by using this graph. But you can tell me about the change in the concentration, but you cannot tell me about the concentration itself. But here, we are talking about concentrations, and in this we are talking about the rates right. But they are connected right. Do you see this? Stds: Yes Lerato: Alright. secondly, we can see very clearly that these are concentrations of reactants and these are concentrations of the products right. From the graph, you can see clearly, these are not the equal but not changing right. And they cannot be the same because we know about collision theory right. They can't be the same. If they were the same, then we would be having something, we would be having this (constant nature similar to that on rates), here. Secondly in the flask, we would have round about the same amount of things... Em we are gonna talk about that later right, which is something to do with the Kc. Um, the equilibrium constant or equilibrium quotient. This is, it just tells you the ratio between your products and your reactants right. So it is denoted like this (writes on the board) ...at equilibrium right, we can tell (writes Kc = [products]/[reactants]. There is a specific ratio that these are gonna follow right. Because it makes sense, if we do not disturb anything, it means these things are always gonna be the same right. So, if you put the same number over another number at the bottom, then it should stay the same, right. So, if two over three is two over three forever, it will always be two over three forever. Makes sense, right? Stds: yes	**Overview:** Highlighting the differences between concentration and rate versus time graphs and emphasizing that rates are equal whilst concentrations are constant at equilibrium. Kc is also used to underline the fact that the concentrations at equilibrium do not necessarily have to be constant. **Qualitative in-depth analysis:** The episode is initiated by the learner's misunderstanding of the differences between the rate and concentration time graphs (LPK). To address this difficulty, Lerato differentiated between rate and concentration (CS), also pointing to the fact that with rate calculated as concentration over time, it is evident that the concentration time graph is used to derive the rate time graph (WD). He then uses the calculation of Kc (a symbolic Representation-R) to emphasize on the constant nature of concentrations at chemical equilibrium versus equal rates (CS). The episode presents a four-component interaction in a discussion that aimed at explaining the difference between the rate and concentration time graphs as displayed in the TSPCK map below. **A Sophisticated TSPCK episode: LPK-CS/WD/R/CS** 
<u>Concentration versus time graph for the Haber process:</u> 77-80 mins **Lerato:** writes an equation on the board; $N_2 + H_2 \leftrightarrow NH_3$. Is it balanced? Stds: No Lerato: What do we need? Stds: 2 Lerato: Two on what? Stds: NH3 Lerato: Ok...	**Overview:** Draws and explains a concentration versus time graph using the actual chemical reaction made up of two reactants and pointing out precisely the area within the graph which denotes the state of chemical equilibrium. **Qualitative in-depth analysis:** Lerato begins this teaching segment by displaying a symbolic equation on the board and asks students to balance it (LPK). The teacher probes

Stds: Three on hydrogen **Lerato:** Great, now it is balanced. Now we are going to draw the concentration versus time graph for this reaction. What is the unit for concentration? **Stds:** Mole per cubic decimeter **Lerato:** Ok, time could be seconds, minutes... So, I will just put per unit time right. So, unit of time can be minute, seconds, hours, days years, centuries... So, what can we say about the concentration of NH_3, ammonia right at the beginning? Where do we put in on the graph? Stds: lower Lerato: It is somewhere there (indicates its position on the graph). Ok, assuming that we put em, a lower concentration of H2. It is lower than N2, it is lower than nitrogen. The hydrogen gas that we put is lower than the nitrogen. Where will it be in the graph? Stds: Between Lerato: It is in between; somewhere here (denotes its position on the graph). Yeah, let us draw the shape. And we know the general shape of how products must be, right? Ok, let us start with the product right. (Draws the graph showing how different concentrations for all reagents change until chemical equilibrium has been reached). So, this will be our equilibrium where concentrations are constant; not changing.	students throughout the episodes as he draws the concentration versus time graph (R), and deliberately pointed where on the graph is chemical equilibrium is demonstrated as denoted by constant concentrations (CS). The episode shows an interaction between three different TSPCK components as displayed in the TSPCK map below. **Proficient TSPCK episode: LPK-R/CS** 
<u>Factors affecting chemical equilibrium-concentration effect:</u> 80-87 mins **Lerato:** So, we have our reaction already at equilibrium, and this is how we represent it on a concentration time graph. So now we want to see what happens when you change those conditions that we said should be constant, temperature, pressure and concentration. Let us begin with concentration. What will happen to this graph if we increase the concentration of nitrogen? **One std:** Increase **Lerato:** What will increase? **Same std:** products that are formed **Lerato:** We expect an increase. Because it was this particular amount then we added this amount right. But we know that reactions follow this pattern, this function (referring to how the graph has been presented before a disturbance). So we expect that it should follow the same function right. Because always, it's in a closed system so it always wants to come back to this equilibrium. It always wants to come back because you know; we are not really taking anything out. So, this is still in a closed system, and it is still a reversible reaction, so which means it still has to follow the same kind of behavior that it was doing before we started this whole process of adding something or doing something right. On the other hand, the concentration of hydrogen decreases, as more of it reacts with the added nitrogen (draws the whole graph with concentrations of all reagents constant at some point). So, like I said, the reaction will re-establish another chemical equilibrium as shown on the graph.	**Overview:** Factors affecting chemical equilibrium introduced; the impact of increasing the concentration of one reactant to the equilibrium position explained. A concentration versus time graph used to explain the effect of the disturbance. **Qualitative in-depth analysis** Lerato introduces factors that affect chemical equilibrium and begins a discussion on the effect of increasing the concentration of a reactant (CS). He then emphasized on how an increase in this concentration effects the concentrations of other reagents in the system also indicating that the reaction will always re-establish an equilibrium position even after a disturbance (WD) demonstrating how that change is represented on the graph (R). The episode shows an interaction between three different TSPCK components as displayed on the TSPCK map below. **A proficient TSPCK episode: CS/WD/R** 
<u>Explaining the spike on the concentration time graph on changing the concentration of one reagent:</u> 87-90 mins **Lerato:** So why is there a short spike for nitrogen like I have shown on the graph here? Why do we not see the same for hydrogen and ammonia? What causes the spike? Remember our equation is $3H2 + N2 \leftrightarrow 2NH3$. **Stds:** Silence **Lerato:** So, we added nitrogen, hence its concentration increase was instantaneous; but reactions don't have like, they don't have the instantaneous act. Because of this, some collisions are not effective or successful, some are, some are not, you understand the whole process of, and it is a gradual process. It is not a process of just, you put staff inside and then everything reacts effectively. So, very few reactions that happen like that. But even that, at a molecular level the time it takes is not instantaneous right. So, under those circumstances that is the answer, because of 1. We did not remove anything here, right. So, it cannot be a sharp spike down in a graph. 2. There is a gradual decrease because of the fact that there is still a reaction happening, so we need to use up some of the concentration of each which is still available.	**Overview:** Explains the spike as caused by an instantaneous addition of nitrogen as opposed to a gradual change in concentrations of other reagents, such as a decrease in hydrogen and an increase in ammonia. **Qualitative in-depth analysis:** Lerato refers students' attention to a rapid increase/spike for nitrogen on a graph (R) and asks them to explain the cause. He also refers students to the overall equation that the graph was drawn from (LPK). To explain this, Lerato indicates the spike as affected by the instantaneous addition of nitrogen in the system, which is different for other reagents which only change based on the rate of effective collisions (WD). Three components are evidently interacting in this episode as displayed in the TSPCK map below. **A Proficient TSPCK episode: R/LPK/WD** 
<u>Checking learner understanding on the effect of changing concentration:</u> 90-93mins **Lerato:** Ok let us see if we understood. What do you think will happen when we increase Hydrogen? **One std:** There will be a sharp increase **Lerato:** There will be a sharp increase, and what will happen to the concentration of nitrogen? **Stds:** It will go down **Lerato:** It will decrease, and what will happen to ammonia? **Stds:** It will increase **Lerato:** Draws the graph displaying all the changes until equilibrium is re-established. I hope you understand what is happening. (Draws vertical dotted lines in a newly drawn graph after a disturbance). So, point is another equilibrium that is different from the equilibrium before is going to be established right. So, do you see that? Stds: Yes	**Overview:** Checking learner understanding on how the change in concentration affects an equilibrium position, and how this affects the graph. Explains further that the reaction never really stops because equilibrium is re-instated, as long as the system remains closed. **Qualitative in-depth analysis:** The segment involves Lerato evaluating the learners' understanding on the effect of concentration change on chemical equilibrium (LPK), as he demonstrates the changes on the graph and intentionally drew the dotted lines to emphasize on the position of equilibrium (R). Further emphasis by Lerato points out on the importance of always keeping the system closed, which then implies that a reaction at chemical equilibrium will never come to an end (which is a common learner

Lerato: Do we all see that? So, which means you never really stop, you just keep getting special moments in the life of a chemical reaction where it looks like it stopped but in fact it hasn't stopped. So, it just stays, unless you decide that know, I think I'm gonna change something, then a change happen right. So, we just saw how concentration affects chemical equilibrium.	misconception-LPK), even after a disturbance, since chemical equilibrium will always be re-established (WD). This is a three component TSPCK episode with one component observed repeating as displayed in the TSPCK map below. **A Proficient TSPCK episode: LPK/R /WD/LPK** 
<u>The effect of changing pressure on chemical equilibrium:</u> 93-98 mins **Lerato:** Let us move on to the effect of pressure. So only gases are affected by pressure, right? So what do you think will happen when we reduce the volume of our reaction? **One std:** The pressure will increase **Lerato:** Why does the pressure increase? **Another std:** Response not captured by audio **Lerato:** That was brilliant. So, because of these collisions of the particles with the sides of the container/reaction system, there is going to be a force that happens there right. And that force translates to pressure. It's effectively pressure because pressure is force per unit area right. I think you do that in matric or you have done it? So, force has to do with the amount of area. That is the amount of force that really exists. So, if we decrease the area, right, inverse proportionality right, (writes the formula of finding pressure on the board- P=F/A). By decreasing the volume, we are decreasing the Area right. Because there is less space in between the particles to move within space right. So, the molecules will run through to the side of the container more right. At the same time, we are also decreasing the area because as we know, (writes the formula of calculating Volume-V=AXh). So, if you decrease the area you are also decreasing that (the V on the formula) righto, so now we know for sure that pressure has to increase if we decrease the volume right. Let us make an example with this reaction; $N_2 + 3H_2 \leftrightarrow 2NH_3$. We have one mole of N_2 and 3 moles of H_2 right vs two moles of NH_3. Eh you are going to have, because the collision of particles increases, they are going to have a better change of actually producing more products right. So, we know if we are going to decrease the volume, it favors the side that has most moles right and that's our rule. We decrease the volume, which means we increase the pressure, we are going to favor the side that has most moles right. If we do the opposite right, if you increase the volume, therefore decreasing the pressure, you are going to favor the side with less moles right, because now, because the most moles right, they need to now travel much faster (referring to N_2 and H_2). And these ones, they only need only two of themselves (referring to NH_3 molecules on a balanced equation), to bond right. They only need two NH_3's to collide with one another right. On the other hand, the forward reaction would need all the four molecules to collide, and that will not be easy in a larger space.	**Overview:** To explain the effect of changing pressure on chemical equilibrium, the relationship between pressure and volume are emphasized by relating pressure to area and then to volume. The Haber process reaction used to further explain the effect of reducing volume, indicating how the reaction will shift. **Qualitative in-depth analysis:** Lerato begins this by tapping into students' prior understanding of the relationship between pressure and volume (LPK) by asking them what effect reducing the volume of a system will have on the reaction. He affirms the students' responses and expanded on them by emphasizing on the relationship between pressure and volume (CS) using equations of calculating pressure and volume (R). He then uses the Haber process reaction to explain the effect of increasing pressure on the reaction where the reaction with the most moles is favored which in this case is the forward reaction whilst decreasing it favors the side with the less moles-the reverse reaction (WD). This is a four component TSPCK episode with components interacting as demonstrated on the TSPCK map below. **A Proficient TSPCK episode: LPK-CS/R/WD** 
<u>The importance of balancing chemical equations:</u> 98-101 mins **One std:** So sir does it mean that eh, four moles must bump into each other at the same time? **Lerato:** Yes. Let us think about it right. Stoichiometry tells us that things must react at a fixed ratio to produce a product, and that's why you can't move forward if you haven't balanced your equation because you can't produce, remember before, we couldn't, if one mole of this and one mole of this bump into each other, they cannot form NH_3 (referring to moles of N_2 and H_2 respectively). Right, let's think about it, they are going to form something else because they are not in the same ratio and proportion. And that's why it is important to understand that everything that you do in chemistry is connected. And it fills in the doors that the other one couldn't, right. So, collisions have to happen in this ratio for this to happen. That's why when we define a compound, eh an element I think, we say it must combine, no I think it was a compound, we say it must be in specific ratios. Something like that. We had that part of the definition because it is important. Because you can't produce any stream without having these in that proportion combining to give you two molecules of this.	**Overview:** Explaining the importance of balancing equations to indicate the significance behind ratios and right proportions when representing chemical equations. **Qualitative in-depth analysis:** The episode is prompted by a learner question with respect to how chemical reactions occur (LPK). What triggered the learner to ask this question was the explanation by Lerato when he argued that four molecules of gases (one N_2 and three H_2) as per the balanced equation, needed to collide effectively in order to form 2 moles on ammonia. Lerato then emphasized this by arguing that every reaction happens at a fixed ratio and that even compounds formed do so at a fixed ratio which determines the correct formula of the compound (CS). The use of and reference to the reaction introduced another component on symbolic representations (R). The episode displays three components that are evidently interacting in this teaching segment as shown on the TSPCK episode below. **A basic TSPCK episode: LPK-CS/R** 
<u>Presence of and lack of a spike on a concentration time graph after a disturbance:</u> 101-102 mins **Lerato:** Points students to the structural differences of graphs as a result of a disturbance of chemical equilibrium. One thing to note that is different between graphs of temperature and pressure, from where you increase or decrease the concentrations right, is that there is no	**Overview:** The segment is about the changes on the graph as affected by the disturbance of chemical equilibrium through changes in concentration, pressure and temperature. **Qualitative in-depth analysis:**

spike right (Referring students to the graphs drawn earlier). Do you understand why there is no spike? It's because we are not taking anything away or adding anything. There is only a gradual increase or decrease of reagents depending on whether we have increased or decreased the pressure or temperature. This is how the graph after increasing pressure for a Haber process reaction would look like (draws the graph).	The explanation begins with an emphasis on the change in the structures of the graphs when a chemical equilibrium position is disturbed; a difficult concept for the students to understand (WD). Lerato explained this further by demonstrating the effect of change in pressure on a graph and differentiating it from the change seen when the concentration is changed. Graphs are a form of representation (R). Two components are evidently interacting in this episode as displayed on the TSPCK map below. **A Basic TSPCK episode: WD/R** 
<u>The effect of increasing temperature on chemical equilibrium:</u> 102-110 mins **Lerato:** Ok, the last factor is temperature right and temperature has to do with what type of reaction we have. So, I don't know if typically, you have seen that reactions occur differently. **Lerato:** Have you seen that some reactions produce energy in the form of heat whilst other reactions need you to add some heat for them to take place. Like we need to add some energy into your system for this reaction to take place, right. Let us give an example; have you ever wondered why sometimes you need to boil certain things for reactions to happen. Like You need to, you guys have to use the Bunsen burner; sometimes you have to put in some heat for something to happen right. Some need while some release heat afterward right. And typically, examples will be fireworks right. Have you thought about how the fireworks operate? Explosives and nuclear energy which is another thing right. Some of those chemical reactions, they release heat. You didn't put any heat in them. So, we classify those under exothermic and endothermic reactions, right? So, the word "exo", you know exoskeletons, exo-something, something. So that means outside right. So, think of exo as release. Endo means in. So, energy is put in, into the system. So, if they say a reaction is an endothermic reaction, it means energy is being put in, right. And if it is an exothermic reaction, energy is leaving, it is going out of that thing, right; you do remember this? So, if we were to say a reaction A + B, going into C was exothermic (writing the reaction as he speaks), where do you think energy will be put in in an equation? Stds: Where? Lerato: Ok, let us think about it, so in one we are putting in energy, what do we call that thing that we normally put in? In a reaction, what do we call that thing that we put in? One std: Reactants Lerato: Reactants, right. So, a nice way to think about it and also to help you in answering questions right, you got to think about these reactions as if you actually put in the energy as a reactant right; (writes an equation- A + B + enthalpy H ↔ C) ... So here energy is like a reactant right. So, this is case one where energy is absorbed or put in for the reaction to occur. This happens for endothermic reactions. For case 2 (D + E ↔ F + enthalpy H), energy is released, so it is added as a product. This is the case for exothermic reactions because they give out heat energy, they produce energy. So here energy is like a reactant, and in the second one it is like a product right, because it is released. And because we basically treat it as a reactant, it means the same rule for concentration will still apply right. If we increase energy or we increase the temperature, we have effectively increased the energy right. If we increase the temperature in this case it means we increase the reactant. What does that mean? It means more products are going to be produced right. Ok, in this case and we increase the temperature; it means we have effectively increased energy, so the reaction that uses that energy which is an endothermic reaction will be favored.	**Overview:** A quick review on examples and characteristics of endothermic and exothermic reactions. Demonstrates using an arbitrary reaction, where energy is added when a reaction is endothermic versus when it is an exothermic reaction and emphasizes on the effect of increasing temperature versus a decrease in temperature on a reaction that has reached chemical equilibrium. **Qualitative in-depth analysis:** A review on exothermic and endothermic reactions taps into learners' previously learnt concept (LPK). Students are made aware of important characteristics of endothermic and exothermic reactions to consider before deciding on equilibrium shift as affected by change in temperature (CS). Lerato uses a chemical equation (symbolic representation- R), to explain the effect of change in temperature on chemical equilibrium position where students have to treat the increase in temperature like an addition/increase in concentration of a reagent and the decrease/release of temperature like a decrease in the amount of a reagent (WD). Four components are interactively used in this teaching segment as displayed in the TSPCK map that follows. **A Sophisticated TSPCK episode: LPK/CS/R/WD** 
<u>A summary on chemical equilibrium discussions:</u> 110-117 mins **Lerato:** In summary, we learnt what chemical equilibrium is, right? We first learnt how a reaction happens. Then we established that ok, they happen in collisions, but two things; collisions must have sufficient energy and they must collide in the right orientation. The reaction should also be in a closed system, because if it is open, we are going to lose mass right and that the reaction should be reversible. And after that we learned about chemical equilibrium which we explained using two graphs; the rate and concentration versus time graphs presented over there. We said when the reaction reaches chemical equilibrium right, the concentrations of both reactants and products are constant. When we talked about equilibrium, we also said the rate of the reverse reaction is equal to the forward right. So, what is important is that we said, 1, the concentrations are not the same, right. That is what we highlighted. Concentrations are not the same at equilibrium. For a particular reactant or product, it stays the same over time, but all of them together, they are not the same. So H_2, N_2 and NH_3 do not have the same concentrations at equilibrium as you can see on the concentration versus time graph over there. They just stay constant for each. For H_2, it is the same concentration at equilibrium, right (demonstrating the constant nature with his hands). So they are not equal, but the rates are equal. Then we moved on and talked about what disturbs equilibrium; change in concentration, pressure and temperature and for example, we said; if I change the concentration of one reactant, then more products will form. But obviously, if there are two reactants, the other reactant will decrease because it is going to react. So, if we have two reactants and increase the concentration of one, it will collide with this one, and this one will decrease and this one will also decrease of cause after you added	**Overview:** Summary of the lesson, highlighting what was discussed throughout the topic. Emphasis on important conditions of chemical equilibrium that were discussed; closed systems and reversibility of reactions and highlighted on the two graphs discussed, one on rates and the other on concentrations. Further emphasis is made on concentrations being constant at chemical equilibrium, with reference to an earlier graph that displays unchanging concentrations of N2, H2 and NH3, which are not equal per say. He then explains the effect of a disturbance on chemical equilibrium. **Qualitative in-depth analysis:** This teaching segment summarizes what was learnt throughout the topic, by first touching on important conditions necessary for chemical equilibrium to occur (CS). Reference is also made onto the graphs used in explaining chemical equilibrium; rate and concentration time graphs (R), and emphasis on concentrations being constant rather than equal (LPK) using symbolic representations (R). The summary ends with the discussion on the effect of adding a disturbance on chemical equilibrium, and how the equilibrium position is affected (WD). Four different components with one repeating are interactively used in this episode as displayed in the TSPCK map below. **A Sophisticated TSPCK episode: CS/R/LPK/R/WD**

it, and then it is going to give you a new value right of concentrations which will correspond with the new equilibrium Secondly, we spoke about how pressure and volume are related right. And how when you decrease pressure you increase volume. If you decrease pressure it increases volume, and how it affects the collisions of staff in the reaction vessel and then ultimately how it affects this graph And temperature affects equilibrium because it acts as if you are putting in or taking out energy. If you decrease temperature, you are taking out the energy from the system Whether you are increasing or decreasing, it will affect it as if you have added concentration right.	
<u>The Le Chatelier's Principle explained</u>: 117-120 mins Lerato: So just to conclude, what we have been discussing about the factors that affect chemical equilibrium; there is a principle that talks to that, which is referred to as the Le Chatelier's Principle. The Le Chatelier's Principle states that, when a disturbance is added to a reaction at a chemical equilibrium, it acts in such a way that it counteracts the added change. It goes against the change. So, the same things that we have been doing with effects of pressure, of temperature. That is what Le Chatelier's is talking about. If I have reached equilibrium, I add concentration, which is the disturbance now, right. I am disturbing it from being at equilibrium and it is going to act in such a way that it will reverse that change. And that is why, remember, you add, and then there is a decrease right. You add and then there is a decrease of reactants and an increase of products. Eventually the reaction will reach a new state of equilibrium. And remember we said when you divide the concentrations of products to reactants at chemical equilibrium, we should expect no change as the concentrations of all reagents will be constant. That is what we called Kc. Do you understand? Stds: Yeah	**Overview:** Introducing the Le Chatelier's principle to explain the effect of factors that affect chemical equilibrium; using Kc to explain that chemical equilibrium will be re-established which will be seen by constant value obtained when dividing the concentrations of products and reactants. **Qualitative in-depth analysis:** Lerato introduced students to the Le Chatelier's Principle used to explain how a reaction at equilibrium reacts to a disturbance. He then stated the principle in response to the added disturbance (WD) referring back to the examples given earlier about the effect of increasing the concentration of one of the reactants and explaining further that chemical equilibrium is eventually re-established which can be seen through calculation of Kc; the chemical equilibrium constant from the concentrations of reactants and products (CS). Two components of TSPCK are evidently interacting in this episode as displayed on the TSPCK map below. **A Proficient interwoven TSPCK episode: WD/CS** 

Appendix T: Sara's lesson plan

(Topic Specific PCK Lesson Plan)

Subject	Physical Science
Grade	12
Topic covered	Chemical Equilibrium
Specific Concept	The nature and conditions required to achieve chemical equilibrium & The factors affecting Chemical Equilibrium
Allocated time	2 hours

CATEGORY A: ASPECTS RELATED TO CURRICULAR SALIENCY

1. Purpose: (What do you intend the learners to know in this lesson? You can list this as a set of specific outcomes)
   Highlighted on slide number 2.

2. List the <u>most immediate concepts</u> needed prior to teaching the concepts that you intend to teach. Indicate how these genuinely affect your lesson.

   Endothermic and exothermic reactions
   Homogeneous and heterogeneous mixtures/reactions
   Stoichiometry (e.g., Balancing chemical equations, writing out chemical equations…)

3. Summarize your understanding of the most important ***content knowledge*** of **this lesson**.

   Chemical equilibrium is a STATE that takes place in a CLOSED SYSTEM (vs. OPEN SYSTEM) where the RATE of the forward reaction is EQUAL to (the same) the RATE of the reverse reaction (vs. reactions that go to completion). At equilibrium, the CONCENTRATION of the reactants and the products remains CONSTANT. (*The meaning of the words in caps will be elaborated during the lesson*)
   Chemical equilibrium is obtained when the temperature, pressure and concentrations remain CONSTANT.
   There are three main factors that affect the disturb equilibrium (pressure, temperature and concentration) whose resultant equilibrium shift is governed by Le Chatelier's Principle.
   Effect of concentration (aq) & (g) – If the concentration of a reactive is increased the overall reaction rate will increase and the equilibrium position will shift away from the side with an added concentration and that reaction will be favoured.
   If the concentration of a reactive is decreased, the overall reaction rate will decrease, and the equilibrium position will shift towards the side where the reactive was removed (its concentration decreased) and that reaction will be favoured.
   Effect of pressure (g) *note that pressure and volume have an inverse relationship which is governed by Boyle's Law, done in grade 11*

If the pressure of a system in equilibrium is increased (decrease in volume) the equilibrium will shift towards the side with fewer total number of moles.

If the pressure of a system in equilibrium is decreased (increase in volume) the equilibrium will shift towards the side with more total number of moles.

Effect of temperature (aq) & (g) – The effect of a change in temperature is dependent on whether the reaction is endothermic or exothermic, if the reaction is endothermic therefore reverse reaction will be exothermic the temperature is increased then the forward reaction will be favoured as the increase in temperature favours the reaction which seeks to absorb the heat (to result in the temperature not rising as high as expected), therefore equilibrium will shift toward the endothermic reaction.

CATEGORY B: ABOUT LEARNER PRIOR KNOWLEDGE

4. List common misconceptions and errors (made by the learners) which are specific to the concepts intended for this lesson.
    a. At equilibrium, there is no reaction taking place as no reaction is seen taking place at a macroscopic level.
    b. Before chemical equilibrium is achieved the forward reaction must go to completion and then the reverse reaction will start until chemical equilibrium is achieved.
    c. If the AMOUNT (number of moles) of a reactant is increased, its concentration will remain the same.
    d. The concentrations of the reactants and the products must be equal in order to achieve chemical equilibrium.
    e. When equilibrium has been achieved, the rate of the forward reaction is always greater than that of the reverse reaction.
    f. When one of the reactives is added to a chemical system in equilibrium, only the concentration of products increases.
    g. When one of the reactive is added to a system in equilibrium, the equilibrium position will always shift towards the product side.
    h. The concentrations of solids and liquids can be changed by adding more of the substance.
    i. A catalyst affects the equilibrium position and thus the concentrations of reactants and products.

CATEGORY C: ASPECTS THAT ARE DIFFICULT TO UNDERSTAND

5. List specific parts of your lesson that you think may turn out difficult for the learners to understand. Provide the reasons for your analysis.
    a. Terminology – The difference between constant (unchanging) and equal (the same). The difference between what is macroscopic and microscopic.
    b. Relating the concentration vs. time graph with the rate vs. time graph (the rate graph is a 'derivative' of the concentration-time graph).
    c. The idea the forward and reverse reactions are taking place simultaneously when equilibrium has been achieved and not disturbed.
    d. The fact of solids not having an effect on chemical equilibrium.
    e. How pressure affects chemical equilibrium (be it an increase or decrease in pressure).

f. Limitations of Le Chatelier's Principle that most teachers do not expose to their students to.

CATEGORY D: USE OF REPRESENTATIONS

6. List representations that you would use for teaching the concepts intended for this lesson. Provide the reasons why you choose to use them in the manner that you have suggested.

During the course of this 2-hour session I will mainly be using a PowerPoint presentation to conduct the lesson but there are a couple more representations that I will be utilizing. They include:

a) YouTube videos: Given the time constraints, the use of video illustrations shows students real life examples and experiments that cannot be conducted within the classroom because of lack of resources or time constraints. In this lesson I will be using a video showing water in a closed system and how a phase change illustrates a system in equilibrium where the rates of the forward and reverse reactions take place at the same RATE (pitfall of this illustration is that students might assume that the concentrations of the reactants and products must be equal for chemical equilibrium to be achieved). In addition, this video will demonstrate the dynamic nature of chemical equilibrium as well as what we mean when we talk about a closed system.

The second video resource I have is a video showing how a change in concentration will shift the equilibrium position when a system in equilibrium is disturbed (to save time and I do not have the means to do this experiment with students).

b) I will also be making use of ball and stick models where I demonstrate with the help of my students how a system in equilibrium does not necessarily have to have equal concentrations for chemical equilibrium to be achieved, in addition to reinforcing the dynamic nature of equilibrium, equal reaction rates of the forward and reverse reaction, the idea of reversibility and what a closed system is (a little play where the limitations of the analogy will be highlighted)

c) Within the PowerPoint presentation and the lesson, itself especially with coming to establish what chemical equilibrium is, I have made use of the three levels of representation (macroscopic, microscopic and symbolic especially in the video that I chose for phase change showing chemical equilibrium) which I integrated (used as one) in my explanations.

CATEGORY E: SEQUENCE AND CONCEPTUAL TEACHING STRATEGIES

Since I will be teaching a group of matric students who would have covered this concept already in their respective classes, I would open a 10 -minute discussion where I ask students to tell me any and everything that they know about chemical equilibrium. This I will use as the basis to establish the amount of content knowledge that the students have in this broad topic (which most students seem to think centres around K_c calculation or determinations. Additionally, I will pinpoint some of the misconceptions that students have about this topic. I will then highlight the outcomes of this two-hour session where in the first session I will covering the nature and conditions needed to establish chemical equilibrium.

The concept of reversibility in contrast to reactions that go to completion that students have previously been accustomed to prior to covering this concept will then be explored. We will see that a reversible reaction is characterised by a double arrow pointing in opposite directions. This double arrow also characterises a chemical reaction in equilibrium. The graphs on slide three will also illustrate how a reaction goes to completion (all reactants react to form products) and how this differs from a reversible

reaction (that does not go to completion) and how the forward and reverse reaction can be written out, ultimately integrating these to write out a reversible reaction as one. I will then highlight the fact that at equilibrium the forward and reverse reactions happen simultaneously and that this system is not stationary; It is DYNAMIC. I will then propose that for equilibrium to be achieved, the reaction must take place in a CLOSED SYSTEM. I will then ask students what they know about a closed system and if the system is not closed then what it would be (open). We will further define what a closed and open system is with the example of an open can of coke and a closed flask. I will then show students how water in a closed bottle will achieve chemical equilibrium. Where students see macroscopically how water evaporates and eventually condenses, until the rates are equal (you have equal rates, but you will see no change in the water level); where some of the gaseous water will condense and fall back to liquid water (phase change at equilibrium). Here we will write out the chemical formula and phases of water with the double arrow (reversibility and a system in chemical equilibrium. The YouTube video and what is on slide 4 will be used together (for the rate graph to show that when chemical equilibrium has been achieved, the rates are equal). I will also make students aware of the fact that for chemical equilibrium to be achieved and to hold, the CONCENTRATIONS, TEMPERATURE AND PRESSURE in the system must be CONSTANT, compared to the EQUAL rates when chemical equilibrium has been achieved.

I then will write out the chemical formulas of two systems which have differing phases i.e., 2/3) one with one phase throughout and another with several different phases and ask students to tell me what the difference in terms of the phases in these two chemical equations is. I will then ask students to tell me the terms chemical equations with the same phase (homogeneous reactions/mixtures) and those with more than one phase (heterogeneous reaction/mixture). From this point I will move to slide 5 where we define chemical equilibrium using the terms that we have learnt of (nature and conditions required to establish chemical equilibrium).

We will have a 15-minute session where students have an activity (informal)

BREAK……

We will reconvene and go through the informal activity.

We will then highlight that we had established that at equilibrium the temperature, pressure and concentrations of reactions remain constant. We now want to know what would happen if these three are changed or do not remain constant. The Le Chatelier's Principle will be introduced and how it governs a change in the three factors affecting chemical equilibrium will be explained. We will then go through each of the three factors and their effect on the overall reaction rate as well as how the equilibrium position would shift (slides have all the information). When we have established the effect of an added or removed concentration of a reactive, I will show a video highlighting the effect of an added concentration of a reactant and a product and how the equilibrium position would shift (characterised by a colour change). We will then do the effect of pressure using an image analogy of the effect of pressure and with a temperature change, a video will be used to illustrate the effect of temperature on equilibrium (colour change of NO_2 and N_2O_4.

I will then ask students to tell me if they think if I add a catalyst the equilibrium position will be affected and if so, how would it shift. I then put emphasis on the fact that a catalyst does not affect the equilibrium position but merely serves the function of making a reaction proceed faster (decrease activation energy and provides a shorter path).

If time permits, we will do a little activity where students will be grouped in groups of 5 and asked to explain the effects and equilibrium shift the go with one of the three factors that affect chemical equilibrium.

CATEGORY F: ASSESSMENT

Indicate what kind of informal (assessment for learning) will be done, and a brief indication how the concept (s) discussed may be assessed at some other time in relation to others in the topic.

After the completion of the 1st half or session of class, a little informal activity will be done (in the slides) and will be discussed at the beginning of the second session. With what is taught in the second session if time permits, we will have a short impromptu presentation where students will be separated in groups and give a 5-minute presentation on how each of the three factors affects the equilibrium position and which reaction is favoured (forward or reverse).

*** Please note that on the PowerPoint presentation I have added additional notes that the teacher can utilize whilst the lesson is being conducted*** The presentation must be in presenter view to see the notes so that the teacher does not exclude important information that is not in the slides***

Appendix U: Noma's learner Rasch Person and Item Measure (Pre-and post-test)

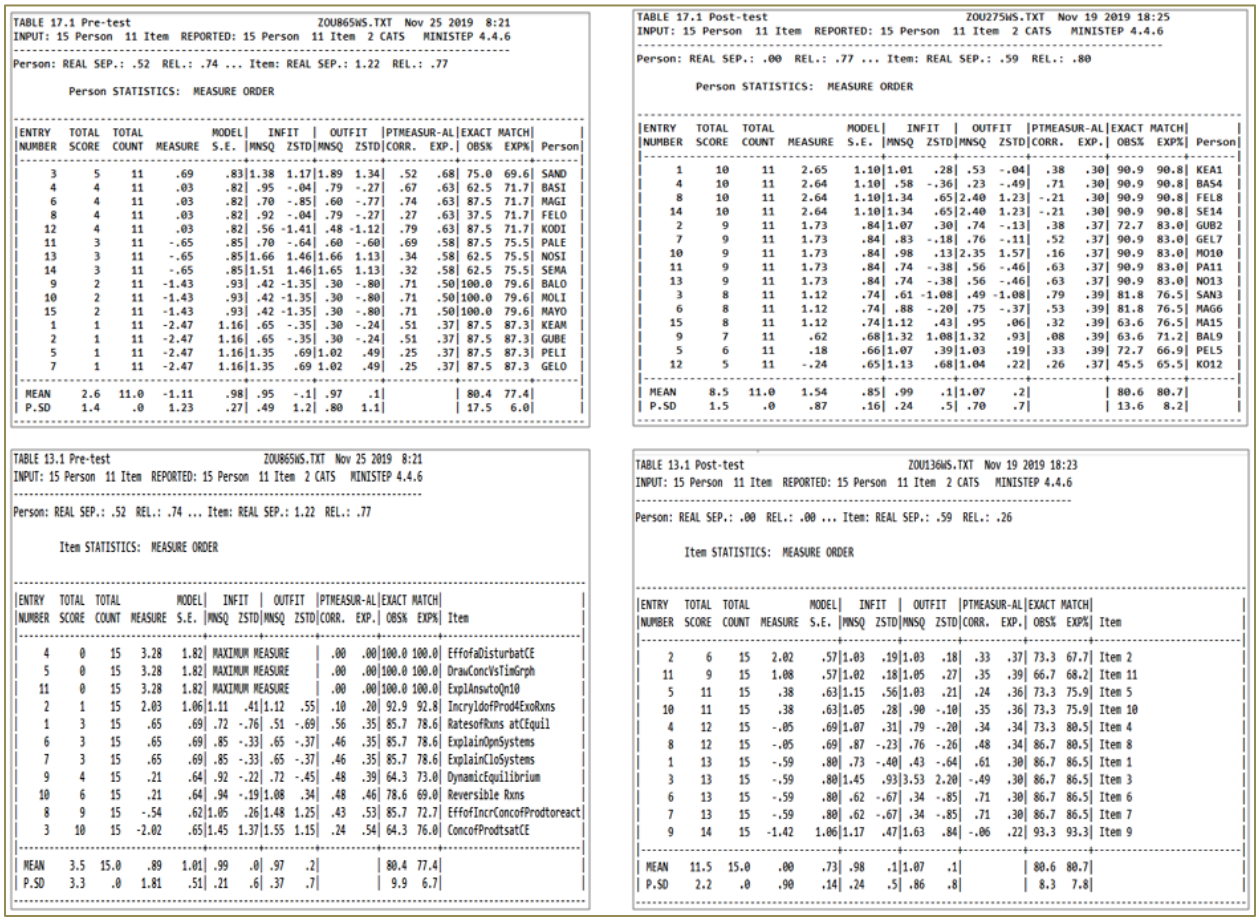


TABLE 17.1 Pre-test ZOU865WS.TXT Nov 25 2019 8:21
INPUT: 15 Person 11 Item REPORTED: 15 Person 11 Item 2 CATS MINISTEP 4.4.6

Person: REAL SEP.: .52 REL.: .74 ... Item: REAL SEP.: 1.22 REL.: .77

Person STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
3	5	11	.69	.83	1.38	1.17	1.89	1.34	.52	.68	75.0	69.6	SAND
4	4	11	.03	.82	.95	-.04	.79	-.27	.67	.63	62.5	71.7	BASI
6	4	11	.03	.82	.70	-.85	.60	-.77	.74	.63	87.5	71.7	MAGI
8	4	11	.03	.82	.92	-.04	.79	-.27	.27	.63	37.5	71.7	FELO
12	4	11	.03	.82	.56	-1.41	.48	-1.12	.79	.63	87.5	71.7	KODI
11	3	11	-.65	.85	.70	-.64	.60	-.60	.69	.58	87.5	75.5	PALE
13	3	11	-.65	.85	1.66	1.46	1.66	1.13	.34	.58	62.5	75.5	NOSI
14	3	11	-.65	.85	1.51	1.46	1.65	1.13	.32	.58	62.5	75.5	SEMA
9	2	11	-1.43	.93	.42	-1.35	.30	-.80	.71	.50	100.0	79.6	BALO
10	2	11	-1.43	.93	.42	-1.35	.30	-.80	.71	.50	100.0	79.6	MOLI
15	2	11	-1.43	.93	.42	-1.35	.30	-.80	.71	.50	100.0	79.6	MAYO
1	1	11	-2.47	1.16	.65	-.35	.30	-.24	.51	.37	87.5	87.3	KEAM
2	1	11	-2.47	1.16	.65	-.35	.30	-.24	.51	.37	87.5	87.3	GUBE
5	1	11	-2.47	1.16	1.35	.69	1.02	.49	.25	.37	87.5	87.3	PELI
7	1	11	-2.47	1.16	1.35	.69	1.02	.49	.25	.37	87.5	87.3	GELO
MEAN	2.6	11.0	-1.11	.98	.95	-.1	.97	.1			80.4	77.4	
P.SD	1.4	.0	1.23	.27	.49	1.2	.80	1.1			17.5	6.0	

TABLE 17.1 Post-test ZOU275WS.TXT Nov 19 2019 18:25
INPUT: 15 Person 11 Item REPORTED: 15 Person 11 Item 2 CATS MINISTEP 4.4.6

Person: REAL SEP.: .00 REL.: .77 ... Item: REAL SEP.: .59 REL.: .80

Person STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
1	10	11	2.65	1.10	1.01	.28	.53	-.04	.38	.30	90.9	90.8	KEA1
4	10	11	2.64	1.10	.58	-.36	.23	-.49	.71	.30	90.9	90.8	BAS4
8	10	11	2.64	1.10	1.34	.65	2.40	1.23	-.21	.30	90.9	90.8	FEL8
14	10	11	2.64	1.10	1.34	.65	2.40	1.23	-.21	.30	90.9	90.8	SE14
2	9	11	1.73	.84	1.07	.30	.74	-.13	.38	.37	72.7	83.0	GUB2
7	9	11	1.73	.84	.83	-.18	.76	-.11	.52	.37	90.9	83.0	GEL7
10	9	11	1.73	.84	.98	.13	2.35	1.57	.16	.37	90.9	83.0	MO10
11	9	11	1.73	.84	.74	-.38	.56	-.46	.63	.37	90.9	83.0	PA11
13	9	11	1.73	.84	.74	-.38	.56	-.46	.63	.37	90.9	83.0	NO13
3	8	11	1.12	.74	.61	-1.08	.49	-1.08	.79	.39	81.8	76.5	SAN3
6	8	11	1.12	.74	.88	-.20	.75	-.37	.53	.39	81.8	76.5	MAG6
15	8	11	1.12	.74	1.12	.43	.95	.06	.32	.39	63.6	76.5	MA15
9	7	11	.62	.68	1.32	1.08	1.32	.93	.08	.39	63.6	71.2	BAL9
5	6	11	.18	.66	1.07	.39	1.03	.19	.33	.39	72.7	66.9	PEL5
12	5	11	-.24	.65	1.13	.68	1.04	.22	.26	.37	45.5	65.5	KO12
MEAN	8.5	11.0	1.54	.85	.99	.1	1.07	.2			80.6	80.7	
P.SD	1.5	.0	.87	.16	.24	.5	.70	.7			13.6	8.2	

TABLE 13.1 Pre-test ZOU865WS.TXT Nov 25 2019 8:21
INPUT: 15 Person 11 Item REPORTED: 15 Person 11 Item 2 CATS MINISTEP 4.4.6

Person: REAL SEP.: .52 REL.: .74 ... Item: REAL SEP.: 1.22 REL.: .77

Item STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Item
4	0	15	3.28	1.82	MAXIMUM MEASURE				.00	.00	100.0	100.0	EffofaDisturbatCE
5	0	15	3.28	1.82	MAXIMUM MEASURE				.00	.00	100.0	100.0	DrawConcVsTimGrph
11	0	15	3.28	1.82	MAXIMUM MEASURE				.00	.00	100.0	100.0	ExplAnswtoQn10
2	1	15	2.03	1.06	1.11	.41	1.12	.55	.10	.20	92.9	92.8	IncryldofProd4ExoRxns
1	3	15	.65	.69	.72	-.76	.51	-.69	.56	.35	85.7	78.6	RatesofRxns atCEquil
6	3	15	.65	.69	.85	-.33	.65	-.37	.46	.35	85.7	78.6	ExplainOpnSystems
7	3	15	.65	.69	.85	-.33	.65	-.37	.46	.35	85.7	78.6	ExplainCloSystems
9	4	15	.21	.64	.92	-.22	.72	-.45	.48	.39	64.3	73.0	DynamicEquilibrium
10	6	15	.21	.64	.94	-.19	1.08	.34	.48	.46	78.6	69.0	Reversible Rxns
8	9	15	-.54	.62	1.05	.26	1.48	1.25	.43	.53	85.7	72.7	EffofIncrConcofProdtoreact
3	10	15	-2.02	.65	1.45	1.37	1.55	1.15	.24	.54	64.3	76.0	ConcofProdtsatCE
MEAN	3.5	15.0	.89	1.01	.99	.0	.97	.2			80.4	77.4	
P.SD	3.3	.0	1.81	.51	.21	.6	.37	.7			9.9	6.7	

TABLE 13.1 Post-test ZOU136WS.TXT Nov 19 2019 18:23
INPUT: 15 Person 11 Item REPORTED: 15 Person 11 Item 2 CATS MINISTEP 4.4.6

Person: REAL SEP.: .00 REL.: .00 ... Item: REAL SEP.: .59 REL.: .26

Item STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Item
2	6	15	2.02	.57	1.03	.19	1.03	.18	.33	.37	73.3	67.7	Item 2
11	9	15	1.08	.57	1.02	.18	1.05	.27	.35	.39	66.7	68.2	Item 11
5	11	15	.38	.63	1.15	.56	1.03	.21	.24	.36	73.3	75.9	Item 5
10	11	15	.38	.63	1.05	.28	.90	-.10	.35	.36	73.3	75.9	Item 10
4	12	15	-.05	.69	1.07	.31	.79	-.20	.34	.34	73.3	80.5	Item 4
8	12	15	-.05	.69	.87	-.23	.76	-.26	.48	.34	86.7	80.5	Item 8
1	13	15	-.59	.80	.73	-.40	.43	-.64	.61	.30	86.7	86.5	Item 1
3	13	15	-.59	.80	1.45	.93	3.53	2.20	-.49	.30	86.7	86.5	Item 3
6	13	15	-.59	.80	.62	-.67	.34	-.85	.71	.30	86.7	86.5	Item 6
7	13	15	-.59	.80	.62	-.67	.34	-.85	.71	.30	86.7	86.5	Item 7
9	14	15	-1.42	1.06	1.17	.47	1.63	.84	-.06	.22	93.3	93.3	Item 9
MEAN	11.5	15.0	.00	.73	.98	.1	1.07	.1			80.6	80.7	
P.SD	2.2	.0	.90	.14	.24	.5	.86	.8			8.3	7.8	

Appendix V: Noma's TSPCK episode Rasch Person Measure

TABLE 17.1 Noma's TSPCK episodes ZOU156WS.TXT Feb 3 2020 14:21
INPUT: 16 Person 5 Item REPORTED: 16 Person 5 Item 2 CATS MINISTEP 4.4.6

Person: REAL SEP.: .00 REL.: .00 ... Item: REAL SEP.: 1.68 REL.: .74

Person STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
2	4	5	2.58	1.88	MAXIMUM MEASURE				.97	.97	100.0	100.0	Nom2
3	4	5	2.58	1.88	MAXIMUM MEASURE				.97	.97	100.0	100.0	Nom3
8	4	5	2.58	1.88	MAXIMUM	MEASURE			.97	.97	100.0	100.0	Nom8
10	4	5	2.58	1.88	.64	-.51	.53	-.60	.77	.64	75.0	75.0	No10
13	4	5	2.58	1.88	.64	-.51	.53	-.60	.77	.64	75.0	75.0	No13
7	3	5	1.16	1.19	.64	-.51	.53	-.60	.77	.64	75.0	75.0	Nom7
4	3	5	1.16	1.19	1.22	.54	1.21	.52	.57	.64	75.0	75.0	Nom4
9	3	5	1.16	1.19	.64	-.51	.53	-.60	.77	.64	75.0	75.0	Nom9
5	3	5	1.16	1.19	.64	-.51	.53	-.60	.77	.64	75.0	75.0	Nom5
12	3	5	1.16	1.19	.64	-.51	.53	-.60	.77	.64	75.0	75.0	No12
14	3	5	1.16	1.19	1.22	.54	1.21	.52	.57	.64	75.0	75.0	No14
16	3	5	1.16	1.19	.64	-.51	.53	-.60	.77	.64	75.0	75.0	No16
1	2	5	-.01	1.03	1.27	1.11	1.30	1.13	.34	.45	25.0	60.0	Nom1
6	2	5	-.01	1.03	1.48	1.81	1.52	1.79	.25	.45	25.0	60.0	Nom6
11	2	5	-.01	1.03	1.48	1.81	1.52	1.79	.25	.45	25.0	60.0	No11
15	2	5	-.01	1.03	1.48	1.81	1.52	1.79	.25	.45	25.0	60.0	No15
MEAN	2.9	5.0	1.04	1.24	.99	.3	.94	.3			60.7	70.7	
P.SD	.6	.0	.76	.25	.36	.9	.43	1.0			22.6	6.8	

Appendix W: Lerato's learner Rasch Person and Item Measure (Pre-and post-test)

TABLE 17.1 Pre-test ZOU149WS.TXT Nov 19 2019 17:27
INPUT: 14 Person 11 Item REPORTED: 14 Person 11 Item 2 CATS MINISTEP 4.4.6
Person: REAL SEP.: .66 REL.: .60 ... Item: REAL SEP.: 1.50 REL.: .73

Person STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
9	7	11	1.23	.79	1.37	1.01	1.36	.66	.42	.58	70.0	77.0	MANE
13	6	11	.63	.76	1.14	.51	1.02	.29	.53	.59	70.0	73.9	TUME
1	4	11	-.50	.77	1.74	1.86	2.69	2.05	.19	.57	70.0	74.4	NALD
11	4	11	-.50	.77	.69	-.90	.51	-.73	.72	.57	70.0	74.4	SILE
12	4	11	-.50	.77	1.12	.44	.89	.04	.55	.57	70.0	74.4	DEKA
3	3	11	-1.13	.83	.68	-.71	.47	-.56	.70	.55	90.0	79.3	TOKA
4	3	11	-1.13	.83	.68	-.71	.47	-.56	.70	.55	90.0	79.3	EMAN
6	3	11	-1.13	.83	1.93	1.87	1.94	1.20	.17	.55	50.0	79.3	DIWE
8	3	11	-1.13	.83	.68	-.71	.47	-.56	.70	.55	90.0	79.3	RABO
14	3	11	-1.13	.83	.56	-1.09	.39	-.76	.74	.55	90.0	79.3	MELI
2	2	11	-1.90	.95	.77	-.23	.48	-.15	.62	.52	90.0	85.7	SELO
10	2	11	-1.90	.95	1.05	.28	1.30	.63	.45	.52	90.0	85.7	LIND
5	1	11	-3.04	1.22	.37	-.81	.13	-.57	.65	.43	100.0	90.8	MPHO
7	1	11	-3.04	1.22	.37	-.81	.13	-.57	.65	.43	100.0	90.8	SEGO
MEAN	3.3	11.0	-1.08	.88	.94	.0	.88	.0			81.4	80.3	
P.SD	1.6	.0	1.14	.15	.46	1.0	.71	.8			14.1	5.6	

TABLE 17.1 Post-test ZOU592WS.TXT Nov 19 2019 17:40
INPUT: 14 Person 11 Item REPORTED: 14 Person 11 Item 2 CATS MINISTEP 4.4.6
Person: REAL SEP.: 1.30 REL.: .73 ... Item: REAL SEP.: 1.25 REL.: .83

Person STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
3	10	11	2.40	1.22	1.66	.99	1.31	.67	.25	.44	71.4	86.6	TOK3
6	10	11	2.40	1.22	1.54	.87	.99	.46	.31	.44	71.4	86.6	DIW6
8	10	11	2.40	1.22	.41	-.78	.20	-.41	.63	.44	100.0	86.6	NAL8
2	9	11	1.24	.98	1.03	.22	1.01	.33	.55	.57	85.7	79.6	SEL2
4	9	11	1.24	.98	.77	-.34	.56	-.23	.66	.57	85.7	79.6	EMA4
5	9	11	1.24	.98	1.24	.62	1.20	1.81	.38	.57	85.7	79.6	MPH5
11	9	11	1.24	.98	.77	-.34	.56	-.23	.66	.57	85.7	79.6	SI11
13	9	11	1.24	.98	.62	-.71	.44	-.44	.70	.57	85.7	79.6	TU13
1	8	11	.37	.90	1.09	.36	.85	-.02	.64	.65	57.1	71.0	RAB1
7	8	11	.37	.90	.65	-.95	.50	-.72	.77	.65	85.7	71.0	SEG7
9	8	11	.37	.90	1.09	.36	.85	-.02	.64	.65	57.1	71.0	MAN9
12	8	11	.37	.90	1.93	2.10	2.95	2.20	.29	.65	57.1	71.0	DE12
14	8	11	.37	.90	.65	-.95	.50	-.72	.77	.65	85.7	71.0	ME14
10	7	11	-.42	.90	.48	-1.45	.40	-.89	.86	.71	100.0	73.9	LI10
MEAN	8.7	11.0	1.06	1.00	.99	.0	1.02	.1			79.6	77.6	
P.SD	.9	.0	.85	.12	.45	.9	.88	.9			14.0	6.0	

TABLE 13.1 Pre-test ZOU149WS.TXT Nov 19 2019 17:27
INPUT: 14 Person 11 Item REPORTED: 14 Person 11 Item 2 CATS MINISTEP 4.4.6
Person: REAL SEP.: .66 REL.: .60 ... Item: REAL SEP.: 1.50 REL.: .73

Item STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Item
11	0	14	3.29	1.83	MAXIMUM MEASURE		.00	.00	100.0	100.0			ExplAnswtoQn10
4	1	14	1.99	1.09	.90	.14	.35	-.16	.42	.28	92.9	92.7	EffofaDisturbatCE
5	1	14	1.99	1.09	.63	-.27	.21	-.39	.56	.28	92.9	92.7	DrawConcVsTimGrph
7	2	14	1.11	.83	.80	-.24	.54	-.20	.52	.36	92.9	86.0	ExplainCloSystems
6	3	14	.52	.72	.98	.08	.81	-.04	.43	.40	78.6	81.3	ExplainOpnSystems
9	3	14	.52	.72	1.21	.61	1.34	.66	.23	.40	78.6	81.3	DynamicEquilibrium
2	3	14	.52	.62	1.15	.62	.98	.11	.36	.44	64.3	72.2	IncryldofProd4ExoRxns
10	3	14	.52	.62	.71	-1.13	.60	-.93	.67	.44	78.6	72.2	EffofIncrConcofProdtoreact
8	6	14	-.73	.60	1.23	1.02	1.35	.97	.25	.45	64.3	69.2	Reversible Rxns
1	8	14	-1.44	.60	.76	-1.04	.68	-.83	.63	.44	85.7	69.7	RatesofRxns atCEquil
3	8	14	-1.44	.60	1.48	1.00	1.92	1.05	-.10	.34	85.7	85.4	ConcofProdtsatCE
MEAN	4.2	14.0	.30	.87	.98	.1	.88	.0			81.4	80.3	
P.SD	3.4	.0	1.73	.35	.26	.7	.50	.7			10.2	8.6	

TABLE 13.1 Post-test ZOU592WS.TXT Nov 19 2019 17:40
INPUT: 14 Person 11 Item REPORTED: 14 Person 11 Item 2 CATS MINISTEP 4.4.6
Person: REAL SEP.: 1.30 REL.: .73 ... Item: REAL SEP.: 1.25 REL.: .83

Item STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Item
4	3	14	2.54	.69	.89	-.18	.98	.15	.41	.33	78.6	78.4	EffofaDisturbatCE
2	9	14	.37	.60	1.00	.08	1.08	.38	.34	.37	71.4	66.8	IncryldofProd4ExoRxns
10	9	14	.37	.60	.79	-.93	.71	-.86	.59	.35	71.4	66.9	EffofIncrConcofProdtoreact
11	9	14	.37	.60	1.07	.37	1.24	.79	.23	.35	71.4	66.9	ExplAnswtoQn10
3	11	14	-.43	.68	1.08	.32	.93	.07	.24	.29	78.6	78.5	ConcofProdtsatCE
5	13	14	-1.78	1.06	1.13	.43	1.54	.79	-.06	.18	92.9	92.8	DrawConcVsTimGrph
9	13	14	-1.78	1.06	1.01	.29	.69	.15	.22	.18	92.9	92.8	DynamicEquilibrium
1	14	14	-3.03	1.82	MINIMUM MEASURE		.00	.00	100.0	100.0			RatesofRxns atCEquil
6	14	14	-3.03	1.82	MINIMUM MEASURE		.00	.00	100.0	100.0			ExplainOpnSystems
7	14	14	-3.03	1.82	MINIMUM MEASURE		.00	.00	100.0	100.0			ExplainCloSystems
8	14	14	-3.03	1.82	MINIMUM MEASURE		.00	.00	100.0	100.0			Reversible Rxns
MEAN	11.1	14.0	-1.10	1.14	1.00	.1	1.02	.2			79.6	77.6	
P.SD	3.4	.0	1.84	.54	.11	.4	.28	.5			8.9	10.8	

Appendix X: Lerato's TSPCK episode Rasch Person Measure

TABLE 17.1 Lerato's TSPCK episodes ZOU612WS.TXT Feb 3 2020 16:23
INPUT: 25 Person 5 Item REPORTED: 25 Person 5 Item 2 CATS MINISTEP 4.4.6

Person: REAL SEP.: .00 REL.: .00 ... Item: REAL SEP.: 2.00 REL.: .80

Person STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
4	4	5	2.81	1.90	MAXIMUM MEASURE				.92	.92	100.0	100.0	Ler4
6	4	5	2.81	1.90	MAXIMUM MEASURE				.92	.92	100.0	100.0	Ler6
24	4	5	2.81	1.90	MAXIMUM MEASURE				.92	.92	100.0	100.0	Le24
15	4	5	2.81	1.90	MAXIMUM MEASURE				.92	.92	100.0	100.0	Le15
20	4	5	2.81	1.90	.89	1.89	.91	2.00	.92	.92	100.0	100.0	Le20
23	4	5	2.81	1.90	.89	1.89	.91	2.00	.92	.92	100.0	100.0	Le23
11	4	5	2.81	1.90	.89	1.89	.91	2.00	.92	.92	100.0	100.0	Le11
1	3	5	1.31	1.24	.91	.02	.66	-.07	.72	.67	75.0	74.8	Ler1
3	3	5	1.31	1.24	.73	-.35	.53	-.26	.76	.67	75.0	74.8	Ler3
5	3	5	1.31	1.24	.73	-.35	.53	-.26	.76	.67	75.0	74.8	Ler5
8	3	5	1.31	1.24	.91	.02	.66	-.07	.72	.67	75.0	74.8	Ler8
10	3	5	1.31	1.24	.73	-.35	.53	-.26	.76	.67	75.0	74.8	Le10
14	3	5	1.31	1.24	.73	-.35	.53	-.26	.76	.67	75.0	74.8	Le14
16	3	5	1.31	1.24	.73	-.35	.53	-.26	.76	.67	75.0	74.8	Le16
17	3	5	1.31	1.24	.91	.02	.66	-.07	.72	.67	75.0	74.8	Le17
18	3	5	1.31	1.24	1.77	1.33	2.73	1.54	.39	.67	75.0	74.8	Le18
19	3	5	1.31	1.24	1.77	1.33	2.73	1.54	.39	.67	75.0	74.8	Le19
21	3	5	1.31	1.24	.73	-.35	.53	-.26	.76	.67	75.0	74.8	Le21
2	2	5	.00	1.11	.40	-1.49	.39	-1.48	.73	.53	100.0	71.8	Ler2
7	2	5	.00	1.11	.40	-1.49	.39	-1.48	.73	.53	100.0	71.8	Ler7
9	2	5	.00	1.11	.40	-1.49	.39	-1.48	.73	.53	100.0	71.8	Ler9
12	2	5	.00	1.11	1.53	1.11	1.57	1.15	.35	.53	50.0	71.8	Le12
13	2	5	.00	1.11	1.41	.91	1.39	.87	.40	.53	50.0	71.8	Le13
22	2	5	.00	1.11	1.53	1.11	1.57	1.15	.35	.53	50.0	71.8	Le22
25	2	5	.00	1.11	1.53	1.11	1.57	1.15	.35	.53	50.0	71.8	Le25
MEAN	3.0	5.0	1.36	1.39	.99	.0	.99	.1			73.6	73.6	
P.SD	.7	.0	1.05	.33	.46	.9	.74	1.0			15.5	1.5	

Appendix Y: Sara's learner Rasch Person and Item Measure (Pre-and post-test)

TABLE 17.1 Pre-test ZOU180WS.TXT Nov 19 2019 18:28
INPUT: 12 Person 11 Item REPORTED: 12 Person 11 Item 2 CATS MINISTEP 4.4.6
Person: REAL SEP.: 1.25 REL.: .61 ... Item: REAL SEP.: 1.99 REL.: .80

Person STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
11	7	11	2.51	1.30	.46	-.83	.22	.37	.84	.79	100.0	85.5	TEKO
9	7	11	2.51	1.30	.46	-.83	.22	-.37	.84	.79	100.0	85.5	MAEK
3	5	11	-.08	1.06	.48	-1.01	.34	-.66	.87	.80	100.0	78.2	ZIMA
4	5	11	-.08	1.06	.48	-1.01	.34	-.66	.87	.80	100.0	78.2	MBIZ
8	5	11	-.08	1.06	.48	-1.01	.34	-.66	.87	.80	100.0	78.2	LESO
12	5	11	-.08	1.06	.82	-.18	.54	-.27	.83	.80	66.7	78.2	KALO
5	4	11	-1.18	1.07	.41	-1.34	.30	-.24	.85	.78	100.0	79.3	TEBO
7	4	11	-1.18	1.07	.41	-1.34	.30	-.24	.85	.78	100.0	79.3	KEKA
10	4	11	-1.18	1.07	1.79	1.34	.30	-.24	.59	.78	66.7	79.3	BUKA
1	3	11	-2.44	1.22	1.65	1.11	1.39	.72	.68	.75	83.3	82.9	LERA
2	3	11	-2.44	1.22	1.81	1.30	2.35	1.17	.64	.75	83.3	82.9	KAMO
6	3	11	-2.44	1.22	1.81	1.30	2.25	1.17	.64	.75	83.3	82.9	TATO
MEAN	4.8	11.0	-.29	1.27	.88	-.3	1.57	.2			90.0	80.9	
P.SD	1.7	.0	2.25	.30	.58	1.1	2.78	1.1			13.3	2.8	

TABLE 17.1 Post-test ZOU462WS.TXT Nov 19 2019 18:32
INPUT: 12 Person 11 Item REPORTED: 12 Person 11 Item 2 CATS MINISTEP 4.4.6
Person: REAL SEP.: 1.30 REL.: .73 ... Item: REAL SEP.: 1.29 REL.: .86

Person STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
2	10	11	2.44	1.19	.44	-.70	.20	-.43	.70	.44	100.0	87.4	KAM2
4	10	11	2.44	1.19	.44	-.70	.20	-.43	.70	.44	100.0	87.4	MBI4
9	10	11	2.44	1.19	1.52	.84	1.08	.53	.24	.44	75.0	87.4	MAE9
10	10	11	2.44	1.19	1.36	.68	.75	.27	.34	.44	75.0	87.4	BU10
12	10	11	2.44	1.19	1.52	.84	1.08	.53	.24	.44	75.0	87.4	KA12
1	9	11	1.34	.94	.70	-.44	.51	-.56	.70	.54	87.5	81.2	LER1
3	9	11	1.34	.94	.52	-.89	.37	-.89	.78	.54	87.5	81.2	ZIM3
6	9	11	1.34	.94	.88	-.06	.75	-.12	.61	.54	87.5	81.2	TAT6
7	9	11	1.34	.94	1.05	.27	1.45	.77	.46	.54	87.5	81.2	KEK7
11	9	11	1.34	.94	1.68	1.23	1.89	1.20	.20	.54	62.5	81.2	TE11
5	8	11	.57	.84	1.25	.70	1.19	.52	.48	.58	62.5	73.8	TEB5
8	8	11	.57	.84	.91	-.10	.93	.01	.62	.58	87.5	73.8	LES8
MEAN	9.3	11.0	1.67	1.03	1.02	.1	.87	.1			82.3	82.6	
P.SD	.7	.0	.70	.14	.43	.7	.49	.6			11.9	4.8	

TABLE 13.1 Pre-test ZOU180WS.TXT Nov 19 2019 18:28
INPUT: 12 Person 11 Item REPORTED: 12 Person 11 Item 2 CATS MINISTEP 4.4.6
Person: REAL SEP.: 1.25 REL.: .61 ... Item: REAL SEP.: 1.99 REL.: .80

Item STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Item
4	0	12	2.06	1.86	MAXIMUM MEASURE				.00	.00	100.0	100.0	EffofaDisturbatCE
9	0	12	2.06	1.86	MAXIMUM MEASURE				.00	.00	100.0	100.0	DynamicEquilibrium
11	0	12	2.06	1.86	MAXIMUM MEASURE				.00	.00	100.0	100.0	ExplAnswtoQn10
5	2	12	1.20	1.20	1.90	1.36	5.70	2.15	.35	.66	90.0	89.4	DrawConcVsTimGrph
7	3	12	1.65	1.00	.26	-1.47	.16	-.60	.86	.70	100.0	87.5	ExplainCloSystems
6	5	12	.09	.80	1.12	.43	1.65	1.03	.61	.67	80.0	76.5	ExplainOpnSystems
2	6	12	-.52	.77	1.06	.30	1.15	.43	.62	.64	80.0	74.5	IncryldofProd4ExoRxns
10	8	12	-1.69	.79	.61	-1.19	.44	-.20	.70	.58	90.0	77.0	EffofIncrConcofProdtoreact
8	9	12	-1.99	1.87	.50	-1.22	.31	-.21	.68	.55	100.0	80.5	Reversible Rxns
1	12	12	-1.99	1.87	.50	-1.22	.31	-.21	.68	.55	100.0	80.5	RatesofRxns atCEquil
3	12	12	-1.99	1.87	.50	-1.22	.31	-.21	.68	.55	100.0	80.5	ConcofProdtsatCE
MEAN	5.2	12.0	.33	1.34	.91	-.3	1.57	.4			90.0	80.9	
P.SD	4.4	.0	3.29	.49	.54	1.1	1.92	.9			8.2	5.6	

TABLE 13.1 Post-test ZOU462WS.TXT Nov 19 2019 18:32
INPUT: 12 Person 11 Item REPORTED: 12 Person 11 Item 2 CATS MINISTEP 4.4.6
Person: REAL SEP.: 1.30 REL.: .73 ... Item: REAL SEP.: 1.29 REL.: .86

Item STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Item
5	8	12	.90	.64	.87	-.48	.80	-.53	.50	.31	66.7	66.5	DrawConcVsTimGrph
11	8	12	.90	.64	1.05	.26	1.05	.27	.25	.31	66.7	69.3	ExplAnswtoQn10
7	9	12	.46	.70	1.39	1.15	1.73	1.45	-.33	.29	75.0	74.9	ExplainCloSystems
2	10	12	-.09	.80	.88	-.09	.67	-.33	.46	.25	83.3	83.3	IncryldofProd4ExoRxns
4	11	12	-.92	1.06	.85	.08	.45	-.26	.47	.18	91.7	91.6	EffofaDisturbatCE
6	11	12	-.92	1.06	.85	.08	.45	-.26	.47	.18	91.7	91.6	ExplainOpnSystems
9	11	12	-.92	1.06	1.05	.33	.89	.27	.14	.18	91.7	91.6	DynamicEquilibrium
10	11	12	-.92	1.06	1.05	.33	.89	.27	.14	.18	91.7	91.6	EffofIncrConcofProdtoreact
1	12	12	-2.18	1.82	MINIMUM MEASURE				.00	.00	100.0	100.0	RatesofRxns atCEquil
3	12	12	-2.18	1.82	MINIMUM MEASURE				.00	.00	100.0	100.0	ConcofProdtsatCE
8	12	12	-2.18	1.82	MINIMUM MEASURE				.00	.00	100.0	100.0	Reversible Rxns
MEAN	10.1	12.0	-.59	1.14	1.00	.2	.87	.1			82.3	82.6	
P.SD	2.3	.0	1.37	.45	.17	.4	.38	.6			10.6	10.1	

Appendix Z: Sara's TSPCK episode Rasch Person Measure

TABLE 17.1 Sara's TSPCK episodes ZOU805WS.TXT Feb 3 2020 14: 3
INPUT: 26 Person 5 Item REPORTED: 26 Person 5 Item 2 CATS MINISTEP 4.4.6

Person: REAL SEP.: .00 REL.: .00 ... Item: REAL SEP.: 3.05 REL.: .90

Person STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
3	4	5	2.22	1.74	.14	-.62	.09	-.72	.96	.75	100.0	92.5	Sar3
7	4	5	2.22	1.74	.14	-.62	.09	-.72	.96	.75	100.0	92.5	Sar7
9	4	5	2.22	1.74	.14	-.62	.09	-.72	.96	.75	100.0	92.5	Sar9
19	4	5	2.22	1.74	4.61	1.92	3.22	1.48	-.06	.75	60.0	92.5	Sa19
20	4	5	2.22	1.74	.14	-.62	.09	-.72	.96	.75	100.0	92.5	Sa20
21	4	5	2.22	1.74	.14	-.62	.09	-.72	.96	.75	100.0	92.5	Sa21
22	4	5	2.22	1.74	5.00	2.00	9.90	1.35	-.49	.75	60.0	92.5	Sa22
24	4	5	2.22	1.74	.14	-.62	.09	-.72	.96	.75	100.0	92.5	Sa24
25	4	5	2.22	1.74	.14	-.62	.09	-.72	.96	.75	100.0	92.5	Sa25
2	3	5	.23	1.15	.70	-.39	.49	-.09	.74	.61	80.0	78.9	Sar2
8	3	5	.23	1.15	.97	.14	.72	.17	.64	.61	80.0	78.9	Sar8
10	3	5	.23	1.15	.97	.14	.72	.17	.64	.61	80.0	78.9	Sa10
11	3	5	.23	1.15	1.10	.36	.87	.31	.59	.61	80.0	78.9	Sa11
13	3	5	.23	1.15	.70	-.39	.49	-.09	.74	.61	80.0	78.9	Sa13
14	3	5	.23	1.15	.70	-.39	.49	-.09	.74	.61	80.0	78.9	Sa14
15	3	5	.23	1.15	.70	-.39	.49	-.09	.74	.61	80.0	78.9	Sa15
17	3	5	.23	1.15	.97	.14	.72	.17	.64	.61	80.0	78.9	Sa17
18	3	5	.23	1.15	.70	-.39	.49	-.09	.74	.61	80.0	78.9	Sa18
23	3	5	.23	1.15	.97	.14	.72	.17	.64	.61	80.0	78.9	Sa23
26	3	5	.23	1.15	1.45	.88	1.92	1.00	.39	.61	80.0	78.9	Sa26
1	2	5	-.92	1.04	.81	-.58	.63	.17	.54	.46	60.0	68.8	Sar1
4	2	5	-.92	1.04	.81	-.58	.63	.17	.54	.46	60.0	68.8	Sar4
5	2	5	-.92	1.04	1.04	.23	.84	.35	.44	.46	60.0	68.8	Sar5
6	2	5	-.92	1.04	1.04	.23	.84	.35	.44	.46	60.0	68.8	Sar6
12	2	5	-.92	1.04	1.29	.98	1.08	.52	.34	.46	60.0	68.8	Sa12
16	2	5	-.92	1.04	1.04	.23	.84	.35	.44	.46	60.0	68.8	Sa16
MEAN	3.1	5.0	.65	1.33	1.02	.0	1.03	.1			79.2	81.3	
P.SD	.8	.0	1.22	.30	1.16	.7	1.89	.8			15.2	9.0	

Appendix Z 1: Inter-rater reliability

Planned TSPCK

Observer A	Rater_1		
Observer B	Rater _2		
	Observer A		
Observer B	2	1	
1	1	2	3 (60.0%)
2	0	2	2 (40.0%)
	1 (20.0%)	4 (80.0%)	5

Weighted Kappa	0.286
Standard error	0.274
95% CI	-0.251 to 0.86

Observer A	Rater_1		
Observer B	Rater _3		
	Observer A		
Observer B	3	1	
1	2	0	2 (50.0%)
3	1	1	2 (50.0%)
	3 (75.0%)	1 (25.0%)	4

Weighted Kappa	0.500
Standard error	0.375
95% CI	-0.251 to 1.000

Observer A	Rater_2		
Observer B	Rater _3		
	Observer A		
Observer B	3	2	
2	1	2	2 (50.0%)
3	0	2	2 (50.0%)
	1 (20.0%)	4 (80.0%)	5

Weighted Kappa	0.286
Standard error	0.274
95% CI	-0.251 to 0.86

Enacted TSPCK

Observer A	Rater_1		
Observer B	Rater _2		
	Observer A		
Observer B	1	2	
1	1	2	3 (55.0%)
2	0	2	2 (45.0%)
	1 (20.0%)	4 (80.0%)	5

Weighted Kappa	0.286
Standard error	0.274
95% CI	-0.251 to 0.92

Observer A	Rater_1		
Observer B	Rater _3		
	Observer A		
Observer B	3	2	
1	2	0	2 (50.0%)
3	1	1	2 (50.0%)
	3 (75.0%)	1 (25.0%)	4

Weighted Kappa	0.500
Standard error	0.375
95% CI	-0.235 to 1.000

Observer A	Rater_2		
Observer B	Rater _3		
	Observer A		
Observer B	3	1	
2	1	2	3 (60.0%)
3	0	2	2 (40.0%)
	1 (20.0%)	4 (80.0%)	5

Weighted Kappa	0.286
Standard error	0.274
95% CI	-0.251 to 0.822

Learner-achievement tests

Observer A	Rater_1		
Observer B	Rater _2		
	Observer A		
Observer B	1	1	
2	1	2	3 (55.0%)
1	0	2	2 (45.0%)
	1 (45.0%)	4 (55.0%)	5

Weighted Kappa	0.286
Standard error	0.274
95% CI	-0.251 to 0.80

Observer A	Rater_1		
Observer B	Rater _3		
	Observer A		
Observer B	3	2	
1	2	0	2 (50.0%)
3	1	1	2 (50.0%)
	3 (50.0%)	1 (50.0%)	4

Weighted Kappa	0.500
Standard error	0.375
95% CI	-0.235 to 1.000

Observer A	Rater_2		
Observer B	Rater _3		
	Observer A		
Observer B	3	1	
2	1	2	3 (60.0%)
3	0	2	2 (40.0%)
	1 (40.0%)	4 (60.0%)	5

Weighted Kappa	0.286
Standard error	0.274
95% CI	-0.251 to 0.80