

INVESTIGATING A MECHANISM FOR TRANSFER OF TOPIC-SPECIFIC PEDAGOGICAL CONTENT KNOWLEDGE IN A NEW CHEMISTRY TOPIC

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By

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DECLARATION

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

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

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

Chris de Jager

A handwritten signature in black ink, consisting of stylized, overlapping loops and a long, sweeping tail that extends to the right.

Signature

Date: 12 / 08 /2015

ABSTRACT

Pedagogical Content Knowledge (PCK) is a knowledge base for teaching that has been shown to be topic-specific. PCK in a particular science topic enables a teacher to pedagogically transform Content Knowledge (CK) to teach that topic. This ability to transform CK for teaching purposes is a version of PCK recognised as Topic-Specific Pedagogical Content Knowledge (TSPCK). TSPCK, like PCK, is not transferable, thus we cannot assume that good pedagogical transformations observed in one topic can be consequently observed in another. In addition it has been shown that the PCK knowledge base for teaching is tacit in nature. This means that most teachers with such a knowledge base are not aware of it explicitly, or how they develop it. The purpose of the study was to explore the mechanism which pre-service teachers used to apply learnt reasoning to transform CK in a new topic.

The study used Mixed Methods as this approach is not limited to a quantitative nor qualitative paradigm. It was located in the methodology class of final year physical science pre-service teachers. The study examined data collected from an intervention that taught students how to pedagogically transform content of Electrochemistry and also data on their efforts to pedagogically transform a new topic which was Organic Chemistry. The data from the topic of intervention and that of transfer was collected in a format of specially designed tools. The findings were compared to oral interviews to achieve triangulation.

The findings of the study indicated firstly that the pre-service teachers demonstrated the same level of quality of TSPCK in the topic of the intervention and that of transfer. Secondly that the mechanism used to pedagogically transform concepts of the new topic of transfer, Organic Chemistry, relied on the component of TSPCK experienced least difficult by pre-service teachers. Pre-service teachers used the component of representations to reason through the other components. Also, that the process of transforming content of a new topic appeared cyclic, where the least difficult component is a starting point each time a component of TSPCK is used. The study closes with recommendations for explicit development of TSPCK in pre-service teacher training programmes.

Key words

Pedagogical content knowledge, topic-specific pedagogical content knowledge, content knowledge, TSPCK tool, TSPCK rubric, transfer of learnt reasoning, topic of intervention, topic of transfer, pedagogical transformation, Rasch statistical analysis, validity, reliability, sample of pre-service teachers

DEDICATION

I would like to thank my wife for supporting me these last two years during my part time studies at Witwatersrand University. Times have gone by where sacrifices had to be made in terms of time that could have been spent together; I thank you for your continuous support and sympathy. I would not be true to myself, if I do not acknowledge my God in helping me complete my studies. You are always faithful. Thank You.

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DECLARATION	ii
ABSTRACT	iii
KEY WORDS	iv
DEDICATION	v
ACKNOWLEDGEMENTS	vi
TABLE OF CONTENTS	viii
LIST OF APPENDICES	xii
LIST OF FIGURES	xiii
LIST OF TABLES	xv
LIST OF ACRONYMS	xvi

TABLE OF CONTENTS

CHAPTER 1: REASONING RELATED TO THIS STUDY

1.1	INTRODUCTION	1
1.2	PREAMBLE	1
1.3	CONTEXT FOR THE STUDY	1
1.4	RATIONALE	2
1.5	PROBLEM STATEMENT	3
1.6	RESEARCH QUESTIONS	3
1.7	PHILOSOPHICAL STANCE OF RESEARCHER	4
1.8	OUTLINE OF RESEARCH REPORT	5

CHAPTER 2: LITERATURE REVIEW

2.1	INTRODUCTION	7
2.2	RESEARCHING PCK IN A TOPIC AT PRE-SERVICE LEVEL	7
2.3	EVIDENCE OF THE UNLIKELY: IMPROVING PCK IN PRE-SERVICE TEACHERS	8
	2.3.1 Explicit instruction on PCK in a topic	8
	2.3.2 Exposure to classroom practice	9
	2.3.3 The effect of combined instruction and exposure to classroom practice	9
2.4	REVIEW OF THE DIFFERENT PCK MODELS AND DISCUSSION ON THEIR SUITABILITY TO THIS STUDY	10
2.5	THE NEED FOR A TOPIC-SPECIFIC MODEL OF PCK	11
2.6	CHOICE OF THEORETICAL FRAMEWORK FOR THIS STUDY	15

2.7	LEARNER DIFFICULTIES IN THE TOPICS OF INTERVENTION (ELECTROCHEMISTRY) AND TRANSFER (ORGANIC CHEMISTRY)	15
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CHAPTER 3: RESEARCH METHODOLOGY

3.1	INTRODUCTION	17
3.2	RESEARCH DESIGN	17
3.2.1	Research method	17
3.2.2	Research strategy	18
3.3	SAMPLE	19
3.4	INTERVENTION	19
3.5	UNDERSTANDING THE TSPCK TOOLS USED AND DATA COLLECTION IN YEAR 1 OF THE LONGITUDINAL STUDY	21
3.6	DATA COLLECTION FOR YEAR 2: MECHANISM OF TRANSFER	25
3.7	ANALYSIS OF DATA FROM COMPLETED TSPCK TOOLS AND INTERVIEWS	25
3.8	A SUMMARY OF THE RESEARCH DESIGN USED	26
3.9	ISSUES OF VALIDITY AND RELIABILITY	26
3.10	ETHICAL CONSIDERATIONS	27

CHAPTER 4: DATA ANALYSIS FOR TOPIC OF INTERVENTION

4.1	INTRODUCTION	28
4.2	MEASURING TSPCK IN ELECTROCHEMISTRY	28
4.3	QUANTITATIVE PROFILES FOR THE SAMPLE	31

4.4	ANALYSIS WITH THE RASCH STATISTICAL MODEL	33
4.5	EXAMPLES OF PERCEIVED ABILITY TO TRANSFORM CK	36
4.6	SUMMARISING THE FINDINGS	37

CHAPTER 5: DATA ANALYSIS FOR TOPIC OF TRANSFER

5.1	INTRODUCTION	38
5.2	MEASURING TSPCK IN ORGANIC CHEMISTRY	38
5.3	QUANTITATIVE PROFILES FOR THE SAMPLE	40
5.4	ANALYSIS WITH THE RASCH STATISTICAL MODEL	41
5.5	EXAMPLE OF PERCEIVED ABILITY TO TRANSFORM CK	43
5.6	SUMMARISING THE FINDINGS	45

CHAPTER 6: THE MECHANISM OF TRANSFER

6.1	INTRODUCTION	46
6.2	SUMMARY OF WHAT HAS BEEN DONE TO THIS POINT	46
6.3	MECHANISM FOR TRANSFER OF LEARNT REASONING	47
6.3.1	Comparing the rank order of difficulty of items across the two topics	47
6.3.2	Looking at engagement with representations for the topic of transfer	48
6.3.3	Looking at reasons behind the formulation of Big Ideas	53
6.4	LOOKING FOR THE MECHANISM FROM INTERVIEWS	56
6.5	ABOUT THE SEQUENCE OF ENGAGING WITH THE TSPCK COMPONENTS	57

CHAPTER 7: DISCUSSION OF FINDINGS FROM THIS STUDY

7.1	INTRODUCTION	62
7.2	SUMMARY OF STUDY	62
7.3	RESEARCH QUESTIONS REVISITED	63
7.3.1	Research questions 1 and 2	63
7.3.2	Research question 3	65
7.3.2.1	<i>The importance of content knowledge</i>	65
7.3.2.2	<i>Representations as a “way in”</i>	66
7.3.2.3	<i>A cyclic interactive process</i>	66
7.4	CONCLUSION ON MECHANISM FOR TRANSFER OF LEARNT REASONING	70
7.5	THE OBSCURE NATURE OF TSPCK	72
7.6	REFLECTIONS ON MY EXPERIENCE	73
7.7	IMPLICATIONS FROM THIS STUDY FOR TEACHER EDUCATION PROGRAMMES	74
7.8	LIMITATIONS OF THIS STUDY	75
7.9	ETHICAL CONSIDERATIONS	75
	REFERENCES	76

LIST OF APPENDICES

Appendix A	Topic of intervention TSPCK tool	80
Appendix B	Topic of transfer TSPCK tool	93
Appendix C	TSPCK rubric for the topic of intervention	103
Appendix D	TSPCK rubric for the topic of transfer	104
Appendix E	Interview schedule	105
Appendix F	Ethics	
	Appendix F1 Information sheet for pre-service teachers	107
	Appendix F2 Informed consent form	109
	Appendix F3 Ethics clearance certificate	110

LIST OF FIGURES

Figure 2.1	Transformative model of PCK taken from Rollnick et al. (2008, p. 1381)	13
Figure 2.2	Modified PCK model of Davidowitz and Rollnick (2011, p. 364)	13
Figure 2.3	TSPCK theoretical framework (Mavhunga and Rollnick, 2013, p. 115)	14
Figure 3.1	Extract from a test item of the TSPCK tool on learner prior knowledge for topic of intervention - Electrochemistry	23
Figure 3.2	An extract of the TSPCK rubric used in scoring Electrochemistry TSPCK tool	23
Figure 4.1	Another extract from a test item of the Electrochemistry TSPCK tool related to learner prior knowledge	29
Figure 4.2	Extract from the TSPCK rubric for the topic of intervention	30
Figure 4.3	Bubble chart for the topic of intervention	34
Figure 4.4	Extract of engagement with learner prior knowledge for QM – topic of intervention	36
Figure 5.1	Extract from a test item of the Organic Chemistry TSPCK tool related to learner prior knowledge	39
Figure 5.2	Extract from the TSPCK rubric for the topic of transfer	39
Figure 5.3	Bubble chart for the topic of transfer	41
Figure 5.4	Extract of engagement with learner prior knowledge for KS – topic of transfer	44
Figure 5.5	Extract of TSPCK rubric for topic of transfer – “what is difficult”	44
Figure 6.1	An extract showing the use of representations when engaging with learner misconceptions	50

Figure 6.2	An extract showing the use of representations in engaging with teacher strategies	51
Figure 6.3	An extract showing the use of representations when engaging with the component of curricular saliency	51
Figure 6.4	An extract showing two pre-service teachers' reasoning related to sequencing of Big Ideas (ANM left, LVM right)	54
Figure 7.1	Extract from learner prior knowledge test item for topic of transfer	67
Figure 7.2	An illustration of the sequence of engagement for the topic of transfer	68
Figure 7.3	Extract from "what is difficult" component for topic of intervention for ANM	68
Figure 7.4	Extract from "what is difficult" component for topic of intervention for KS	69
Figure 7.5	An illustration of the sequence of engagement for the topic of intervention	70

LIST OF TABLES

Table 1.1	Previous national grade 12 final results	2
Table 3.1	Breakdown of what occurred during the intervention	20
Table 4.1	Example of quantitative profile obtained with TSPCK rubric – topic of intervention	31
Table 4.2	Quantitative profile for the sample in the topic of intervention	32
Table 4.3	Summary statistics for the topic of intervention	35
Table 4.4	Rank order difficulty for topic of intervention	35
Table 5.1	Quantitative profile for the sample in the topic of transfer	40
Table 5.2	Summary statistics for the topic of transfer	42
Table 5.3	Rank order difficulty for topic of transfer	43
Table 6.1	Rank order of difficulty of TSPCK components engaged (Electrochemistry)	48
Table 6.2	Rank order of difficulty of TSPCK components engaged (Organic Chemistry)	48
Table 6.3	Representations used in other TSPCK components	49
Table 6.4	Use of different levels of representations when engaging with teacher strategies	52

LIST OF ACRONYMS USED

PCK Pedagogical Content Knowledge

TSPCK Topic-specific Pedagogical Content Knowledge

CK Content Knowledge

CHAPTER 1

REASONING RELATED TO THIS STUDY

1.1 INTRODUCTION

In the first chapter I provide a historical context, as well as give insight into the problem that led to this study in a South African context. I elaborate on how a logistical problem led to three research questions that focussed my study. In order to further contextualise my study, I will position myself philosophically. Lastly, an outline for this research report is given.

1.2 PREAMBLE

Prevalent thinking in educational research in the 1980s focused on pedagogical skills of the teacher during pre-service training programmes. Lee Shulman made a call to the science education community in his seminal paper in 1986 to remember Content Knowledge (CK) and its role in teaching. Moreover, Shulman was interested in the growth of knowledge that enabled experienced teachers to teach in a way that was comprehensible to students as novices. Though research in the field of Pedagogical Content Knowledge (PCK) has continued for almost three decades, researchers today are still uncertain how knowledge that enables pedagogical transformation of CK develops. If a mechanism for growth of this “skill” in teachers can be determined, teacher training programmes can be adapted for preferred outcomes.

1.3 CONTEXT OF THE STUDY

In 1986 Lee Shulman coined the term PCK (Shulman, 1986). At the time there was an ongoing debate regarding whether teaching could be categorised as a profession, and teachers be acknowledged as professionals. Individuals referred to as professionals have a degree of autonomy in their jobs, and refer to a personal knowledge base in order to perform their jobs. It was debated whether teachers had such a knowledge base that informed their teaching practice. The knowledge base that Shulman saw developing in teachers with time originally consisted of subject matter knowledge

(similar to CK), PCK and curricular knowledge (Shulman, 1986). The insight that Shulman afforded the educational research community related to PCK he defined as...*“the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations – in a word, the ways of representing and formulating the subject that make it comprehensible to others”* (Shulman, 1986, p. 9). This knowledge for teaching can form when CK is intentionally transformed through pedagogical reasoning. My study is based on this postulate.

1.4 RATIONALE

Physical Science results of Grade 12 students in South Africa have been dismal for a long time (Meiring and Webb, 2010). Table 1.1 shows that in 2010 only 47.8% of Grade 12 students passed the subject. In South Africa the percentage requirement for passing Physical Science at Grade 12 is 30%. However, as can be seen from Table 1.1 a significant improvement was observed as learner marks steadily increased in successive years after 2010. Though the improvement is noted towards 2013 in Table 1.1, considering university minimum entry requirements of typically 60%, the pattern remains dismal.

Table 1.1: Previous national grade 12 final results

(Source: <http://www.education.gov.za>)

Year	No. wrote	No. achieved at 30% and above	% achieved at 30% and above
2010	205 364	98 260	47.8
2011	180 585	96 441	53.4
2012	178 887	109 700	61.3
2013	184 343	124 206	67.4

Developing PCK as a knowledge base at pre-service level may improve the teaching practice of physical science teachers in South Africa (Abell, 2008).

1.5 PROBLEM STATEMENT

My research problem is situated in extant literature that has shown the nature of PCK to be transformative and topic-specific, and also literature that has shown it to be possible to increase PCK at pre-service level. PCK within a topic allows transformation of specific CK into forms that are accessible to students during teaching. Mavhunga and Rollnick (2013) have shown recently that it is possible to develop PCK in a topic for pre-service teachers. This may have far reaching implications for science education, especially in South Africa where most science teachers generally have a lack of CK which inhibits the transformation process (Rollnick et al., 2008). A proven intervention for the development of PCK in a single science topic used by Mavhunga and Rollnick (2013) took six weeks.

The intervention appeared rich in-depth and rigour, however, it places high demands in terms of time on a typical teacher training programme. Pre-service science teacher development programmes cannot encompass PCK development for all syllabus related topics due to definite time constraints. I therefore ask a question of concern:

How can the benefits of a rigorous and in-depth programme targeting development of PCK in a specific chemistry topic, through explicit discussion of the pedagogical transformation skill, be maximised for continuous transfer across other chemistry topics?

1.6 RESEARCH QUESTIONS

My study was located within a larger longitudinal study on PCK in specific chemistry topics. The Science and Technology division of the University of Witwatersrand has uniformly agreed to implement a specific approach of developing PCK in key topics across the science and technology discipline. In 2013, a year before the inception of my study, an intervention targeting the development of pedagogical reasoning skills was conducted and data collected from fourth year BEd pre-service teachers from Wits University. These pre-service teachers were explicitly taught important considerations on how to reason through the topic of Electrochemistry for teaching purposes. The theoretical framework that was used to transform CK for teaching purposes is called Topic-Specific Pedagogical Content Knowledge (TSPCK)

(Mavhunga and Rollnick, 2013). Following on the intervention, the same cohort of pre-service teachers were asked to engage with a new topic, Organic Chemistry, in order to pedagogically transform their CK for teaching purposes. However, for the topic of Organic Chemistry no assistance was provided in the form of an intervention.

Based on previous preliminary successes, it was postulated that a transfer of “learnt reasoning” will occur from the topic of intervention to the topic of transfer. What is meant by “learnt reasoning” is the learnt skill to transform CK for teaching a particular science topic using the TSPCK framework. My interest then was to first establish the occurrence of the transfer in the topic of Organic Chemistry as anticipated but more specifically, to determine the mechanism of transfer. In view of my question of concern above, I imagined that the understanding of the mechanism will in return inform key elements to be emphasised or added in order to improve efficiency and possibly standardise the intervention for the benefit of the teacher training education community. My research questions were then formulated as follows:

1. To what extent is TSPCK developed in the topic of intervention and that of transfer?
2. To what extent has transfer of learnt reasoning happened in a new Chemistry topic?
3. What mechanism do pre-service teachers use to engage in pedagogical transformation of a new topic in Chemistry?

1.7 PHILOSOPHICAL STANCE OF RESEARCHER

The findings of this study need to be contextualised by my philosophical stance in order to communicate them to the research community in the field of science education. I recognise the validity of Constructivist theories of learning, in that knowledge is constructed both personally and socially in the mind of a learner (Piaget 1964, Vygotsky 1978). What a learner knows is ultimately separated from the way the world really is. However, I also realise that such reasoning tends towards the extreme view of postmodernism. I do not subscribe to a postmodernist view of reality, as our daily experience attests to the validity of shared knowledge among humans and among research communities. People who are not aware of relativist theories

generally do not seem to doubt what they claim to know, if they feel justified in their belief. The polar opposite of relativism is positivism. Theories related to the latter ontological position are also extreme. There is no way to verify truth, and most researchers have accepted this fate of the sciences. My stance on the nature of knowledge and science is directly related to nature of PCK. PCK cannot be verified as absolute knowledge that applies to all teachers in all contexts. However, this does not mean that PCK cannot have value in science education and beyond. The construct of PCK may be helpful in facilitating thinking about CK pedagogically.

Mixed Methods approach is a pragmatic approach to research, and in Chapter 3 I explain why it is a suitable paradigm for this study. My philosophical position therefore is pragmatic which is neither too naïve, nor too sceptical. This philosophical stance allows me to make use of tools for data capture and analysis from multiple paradigms in order to answer the research questions that relates to the tacit construct of PCK in a science topic.

1.8 OUTLINE OF RESEARCH REPORT

Below I give an outline for the seven chapters of this research report.

- Chapter 1 Chapter one provides a historical overview of the PCK construct. In this chapter the problem statement is situated within a South African context. Three research questions are posited in order to facilitate the research design of this study. My philosophical position as the principal researcher is disclosed in order to provide a context for my beliefs which affect all interpretations of data.
- Chapter 2 The literature on which this study builds is acknowledged in this chapter. I elaborate on pedagogical reasoning, and how this concept originally proposed by Shulman (1987) is related to my study. I also refer to learner difficulties with the topics of intervention (Electrochemistry) and transfer (Organic Chemistry).
- Chapter 3 In this chapter I explain my research method and approach, and justify it. I elaborate on the sample used for this study. I also explain how my

study fits within the longitudinal study. I elaborate on the TSPCK tools used and data collected in year 1 of the longitudinal study. I refer to issues of validity and reliability and end the chapter with ethical considerations.

- Chapter 4 I analyse data from written responses (completed TSPCK tools) of the topic of intervention (Electrochemistry) in year 2 of the longitudinal study. I provide quantitative profiles for the sample of pre-service teachers from Rasch statistical analysis. Rank order difficulty for test items of the TSPCK tool is also given. An informative chart provides evidence of the reliability and validity of the TSPCK tool used to capture data in year 1 of the study. The findings of data analysis for the topic of intervention provide partial answers to my first research question.
- Chapter 5 Chapter five has a similar structure to Chapter four, but shows data analysis for the topic of transfer (Organic Chemistry). The findings from data analysis allow me to answer research questions 1 and 2 fully.
- Chapter 6 In this chapter I investigate a mechanism for transfer of learnt reasoning from the topic of intervention to the topic of transfer. Patterns observed in the written response data for the topics of intervention and transfer is further investigated.
- Chapter 7 A discussion of the findings of Chapter six leads to new evidence presented to further support an emerging pattern contributing to mechanism of transfer. I conclude this study by answering the last research question related to a mechanism that explains transfer of learnt reasoning. I re-examine the findings of the study as it relates to the research questions to answer my big question of concern. I conclude by sharing my thoughts on implications for teacher training programmes, and mention limitations of this study as well as the ethical considerations made.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter I situate my study in the context of existing literature. In so doing, I build on findings from existing relevant research in order to add value to the field of ongoing PCK research. The main purpose of the literature review is to choose a theoretical framework in year 2 of the longitudinal study that will allow me to interpret data collected in year 1 of the longitudinal study.

2.2 RESEARCHING PCK IN A TOPIC AT PRE-SERVICE LEVEL

PCK has been said to be knowledge that accumulates in a teacher's repertoire through experience (Loughran and Mulhall, 2006). In a study done by Geddis, Onslow, Beynon, and Oesch (1993) the PCK model of Grossman (1990) was used as a theoretical framework for case studies. Geddis et al. (1993) showed in one particular case study that teaching the chemistry topic of isotopes to school students requires specialised knowledge for teaching which was present with an experienced teacher, but not with a subject matter specialist with little experience. Geddis et al. (1993, p. 582) viewed PCK "*as knowledge that plays a role in transforming subject matter into forms that are more accessible to students*".

In a comparison of observations between the practice of a subject specialist with little teaching experience, and a high school science teacher with twenty years of experience, Geddis et al. identified four areas of PCK that allowed transformation of CK related to isotopes for teaching purposes. These areas or components of the PCK are learner prior knowledge, effective teaching strategies, alternative representations of the subject matter and curricular saliency (1993, p. 583-589).

In addition, Gess-Newsome (1999, p. 63) have shown that pre-service teachers' CK base is generally: "*fragmented, compartmentalized, and poorly organized, making it difficult to access it efficiently when teaching*". Seeing that CK cannot be transformed pedagogically if such CK is not coherent, how can teacher education programmes

attempt to develop knowledge for teaching science topics seen in expert teachers, in pre-service teachers? This has been the concern and focus of the larger study on PCK in specific topics by the science and technology division at the University of the Witwatersrand.

2.3 EVIDENCE OF THE UNLIKELY: IMPROVING PCK IN PRE-SERVICE TEACHERS

2.3.1 Explicit instruction on PCK in a topic

In a study of science pre-service teachers, Mavhunga and Rollnick (2013) has shown that it is possible to develop PCK at pre-service level by exposing pre-service teachers to explicit instruction on how to pedagogically transform specific science topics. A belief that it may be possible to develop such specialised knowledge for teaching at pre-service level stemmed from a hypothesis made in a PhD thesis by Mavhunga (2012). She stated that:

I argue that knowledge needed to reason pedagogically, particularly to transform subject matter content for a given topic should be introduced explicitly in pre-service programmes. Also such explicit instruction will increase both the opportunity for understanding of SMK and the capacity to transform it for teaching purposes. (Mavhunga, 2012, p. 2)

Note that “SMK” in the above quote refers to Subject Matter Knowledge which is also commonly referred to as Content Knowledge (CK). In the study of Mavhunga and Rollnick (2013) a theoretical construct was devised to assist explicit instruction on how to transform CK for teaching purposes at pre-service level. This theoretical construct will be discussed later in this chapter. This emphasis on explicit instruction of pedagogical transformation of CK by Mavhunga and Rollnick (2013) can be traced back to Shulman’s (1987) concept of pedagogical reasoning. Shulman (1987, p. 14) states that “*comprehension alone is not sufficient*”, and argues that pedagogical reasoning is needed in order to take what is known and make it “*ready for effective instruction*”. Shulman identified five aspects of pedagogical reasoning, and explains the most significant factor as follows:

But the key to distinguishing the knowledge base of teaching lies at the intersection of content and pedagogy, in the capacity of a teacher to transform the CK he or she possess in forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students. (Shulman, 1987, p. 15)

The goal of Mavhunga and Rollnick (2013) to develop PCK in a topic at pre-service level is based on the view that the transformation Shulman refers to can be facilitated in an explicit manner.

2.3.2 Exposure to classroom practice

In a study by Bertram and Loughran (2011), a small sample of pre-service teachers were explicitly taught about the construct of PCK before they embarked on a five week practicum. Explicit instruction refers to direct articulation and demonstration of the concept of PCK. For example, the cohort was taught not only about the construct of PCK, and how it is a knowledge base for teaching, but how the components of PCK can be used to reason through CK of a topic pedagogically using CoRes (Content Representations). The practicum required the cohort to prepare at least five physics lessons using CoRes. The latter is a form completed by a teacher that scaffolds pedagogical considerations of topic-specific CK, and therefore PCK development (Loughran, Berry and Mullhall, 2004). The findings from the Bertram and Loughran study indicated that explicit instruction on PCK at pre-service level served the purpose of assisting pre-service teachers to think about their personal development as science teachers. Instead of teacher training programmes providing pre-service teachers with a list of “tips and tricks” related to teaching specific topics, this exploratory study showed the value of “planting a seed” at pre-service level that starts the natural process of pedagogical transformation of CK at an earlier stage (Bertram and Loughran, 2011).

2.3.3 The effect of combined instruction and exposure to classroom practice

In a similar study to that of Bertam and Loughran (2011), Nilsson and Loughran (2011) attempted a more robust methodology in order to observe if there could be value in developing PCK at pre-service level. Pre-service teachers were explicitly instructed on the construct of PCK and then introduced to the CoRe as a means of identifying

aspects of PCK in a science topic. Pre-service teachers had to prepare a physics or chemistry lesson using the CoRe, and subsequent to teaching reflect on the efficacy of using a CoRe in preparing for that lesson. The findings from this study was positive as PCK was developed in this cohort of pre-service teachers (Nillson and Loughran, 2011).

Therefore, though Shulman might not have originally thought it realistic for PCK to be developed at pre-service level, three independent studies have yielded promising results. The aforementioned studies seem to agree that PCK can possibly be developed at an accelerated pace in novice teachers. Therefore, the goal is not to produce novice teachers with a similar teaching skill set as seasoned expert teachers per se, but to “plant a seed” at pre-service level. Such a seed, as Bertram and Loughran (2011) put it, might be explicit instruction on the “why” and “how” of pedagogical transformation of CK.

2.4 REVIEW OF DIFFERENT PCK MODELS AND DISCUSSION ON THEIR SUITABILITY TO THIS STUDY

Shulman’s original model of PCK was transformative in nature where knowledge bases such as pedagogy and CK are distinguished from PCK. Different models of PCK have been developed as researchers interpreted Shulman’s original theoretical construct in diverse ways. Most of these PCK models have a perspective of a practising teacher in mind and are not separate to other known knowledge bases of teachers, such as pedagogy and CK. Despite the fact that many researchers still do not agree on the nature of PCK, it has been described as a powerful theoretical construct for teacher education research (Kind, 2009). If a mode of transforming CK for teaching purposes can be deduced and its implementation be explicitly demonstrated, novice pre-service teachers can possibly be assisted to accelerate PCK development through adapted teacher training programmes.

Transformative models of PCK were constructed by Grossman (1990) and Magnusson, Krajcik and Boko (1999). Grossman identified four knowledge bases of teachers, namely: conceptions of purposes for teaching subject matter, knowledge of student understanding, knowledge of curriculum and knowledge of instructional strategies as characteristics of PCK. Knowledge from the first three previously

mentioned knowledge bases is said to transform into PCK. Components of PCK identified by Grossman are Knowledge of Science Curricula, Knowledge of Assessment of Scientific Literacy, Knowledge of Students' Understanding of Science and Knowledge of Instructional Strategies. Magnusson et al. (1999) proposed a similar transformative model of PCK, but added the component Orientations to Teaching Science. Components of these two transformative models of PCK is subject-specific. For example, knowledge of assessment of scientific literacy encompasses various topics in science. However, Magnusson et al. pointed out that the nature of PCK might be more topic-specific. Van Driel, Verloop, and De Vos (1998) also noted that PCK had a topic-specific nature.

2.5 THE NEED FOR A TOPIC-SPECIFIC MODEL OF PCK

Despite the sentiment shown in the aforementioned quote of Magnusson et al. (1999) that PCK might be topic-specific in nature, the PCK model in his study is subject specific which is not suitable for use in this study. For example, if Magnusson et al.'s model was used as a theoretical framework to research PCK within a topic like Electrochemistry, what would a researcher look for among a sample of pre-service teachers? If pre-service teachers were to show evidence of knowledge of assessment, would the researcher be able to conclude that PCK within a specific topic such as Electrochemistry is present? Knowledge for teaching Electrochemistry relates to specific content to be taught, and not to general knowledge related to assessment. Therefore, generic or subject specific PCK models are not suitable as a theoretical framework when researching PCK within a topic. A more suitable model of PCK is required; one that is topic-specific.

Rollnick, Bennett, Rhemtula, Dharsey, and Ndlovu (2008) performed two case studies in order to observe the bearing of CK on PCK. Their case study methodology used Content Representations (CoRes) and Pedagogical and Professional-experience Repertoires (PaP-eRs) as methodological tools to analyse pre- and post-instructional data (Loughran, Berry and Mullhall, 2004).

Their first case study on two teachers teaching in a disadvantaged school in South Africa found that they lacked in CK which had ramifications on their effectiveness as science teachers. For example, there was a propensity for transmissive teaching styles and a focus on calculations that remained isolated from content (Rollnick et al., 2008). One of the two teachers could not sufficiently link the main ideas of the mole concept with each other, which restricted holistic teaching of the concept. Generally, it was found that very little pedagogical transformation of CK occurred during the lessons which were observed.

The study further presents a case of a teacher who was involved with an access programme run by a tertiary institution (Rollnick et al., 2008). The access programme served to assist post-matriculants who did not obtain the minimum criteria required by Universities for tertiary science based courses. This specific teacher showed evidence of transforming CK for teaching chemical equilibrium. Pedagogical transformations of CK revealed PCK within the topic of chemical equilibrium.

Rollnick et al. (2008) correlated teaching expertise of teachers with four knowledge bases, one of which was “knowledge of subject matter” which is synonymous with CK. This model of PCK is therefore transformative in that CK is transformed for teaching purposes. From Figure 2.1 it can be seen that this transformative model of PCK indicates that teachers draw from four knowledge domains in order to develop PCK. In addition, from Figure 2.1 it can be seen that CK of a specific science topic can be pedagogically transformed with PCK for that topic and witnessed through “manifestations of teacher knowledge”.

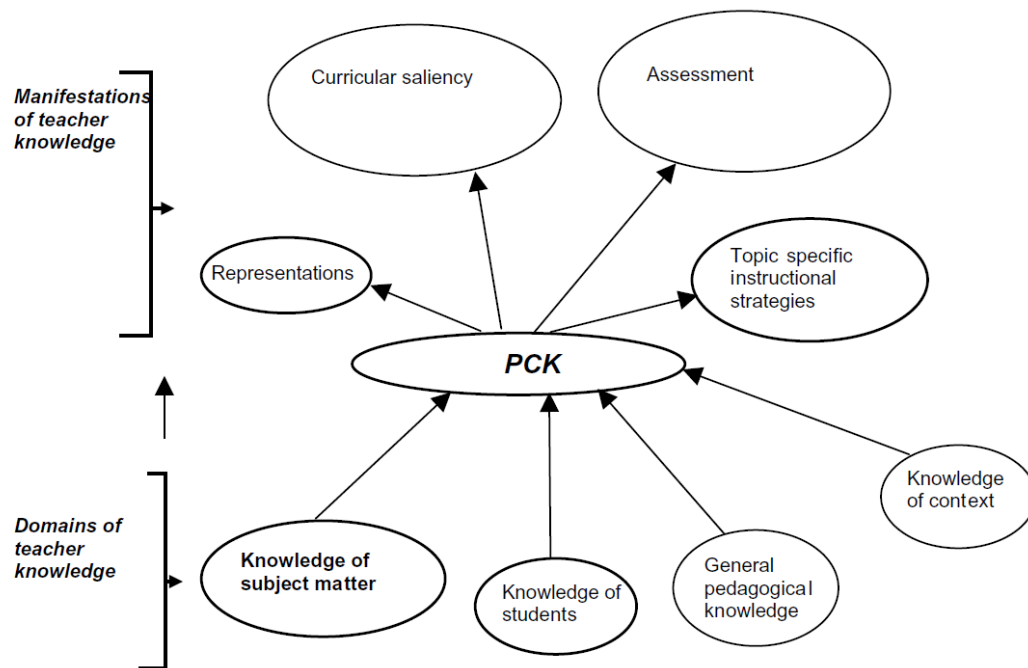


Figure 2.1: Transformative model of PCK taken from Rollnick et al. (2008, p. 1381)

Figure 2.1 shows a PCK model that is transformative and topic-specific. Due to the topic-specificity of PCK individual science topics pose unique challenges for teachers in transforming their CK for teaching purposes. In 2011 Davidowitz and Rollnick did a study that showed the importance of teacher beliefs as underlying the four domains of teacher knowledge. There is a reciprocal relationship between teacher beliefs and the four domains of teacher knowledge in the modified PCK model shown in Figure 2.2.

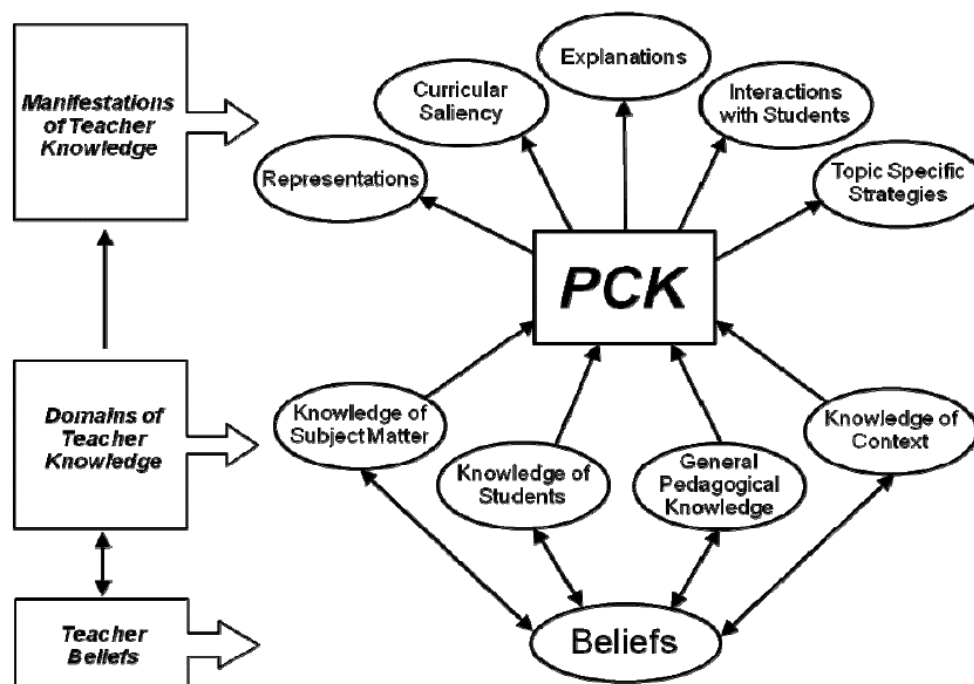


Figure 2.2: Modified PCK model of Davidowitz and Rollnick (2011, p. 364)

My choice of theoretical framework, or PCK model, should have components that can generate measureable knowledge for teaching a specific science topic. This is necessary because year 1 of the longitudinal study involved an intervention that took place where the sample of pre-service teachers was taught explicitly how to pedagogically transform their CK for a chemistry topic. This ability or skill was then measured using a specifically designed data capturing tool. The framework used in year 1 of the longitudinal study had to be able to both generate knowledge of teaching a particular topic in chemistry, and also be used to measure that skill in designing an appropriate data capturing tool. Mavhunga and Rollnick (2013) constructed this theoretical framework based on the model of Rollnick et al. (2008). This construct was specifically designed for the purpose of researching PCK within a topic at pre-service level. Similar to Geddis and Wood (1997), five components were identified for TSPCK: student 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). Figure 2.3 illustrates the TSPCK theoretical framework where “subject matter knowledge” refers to CK.

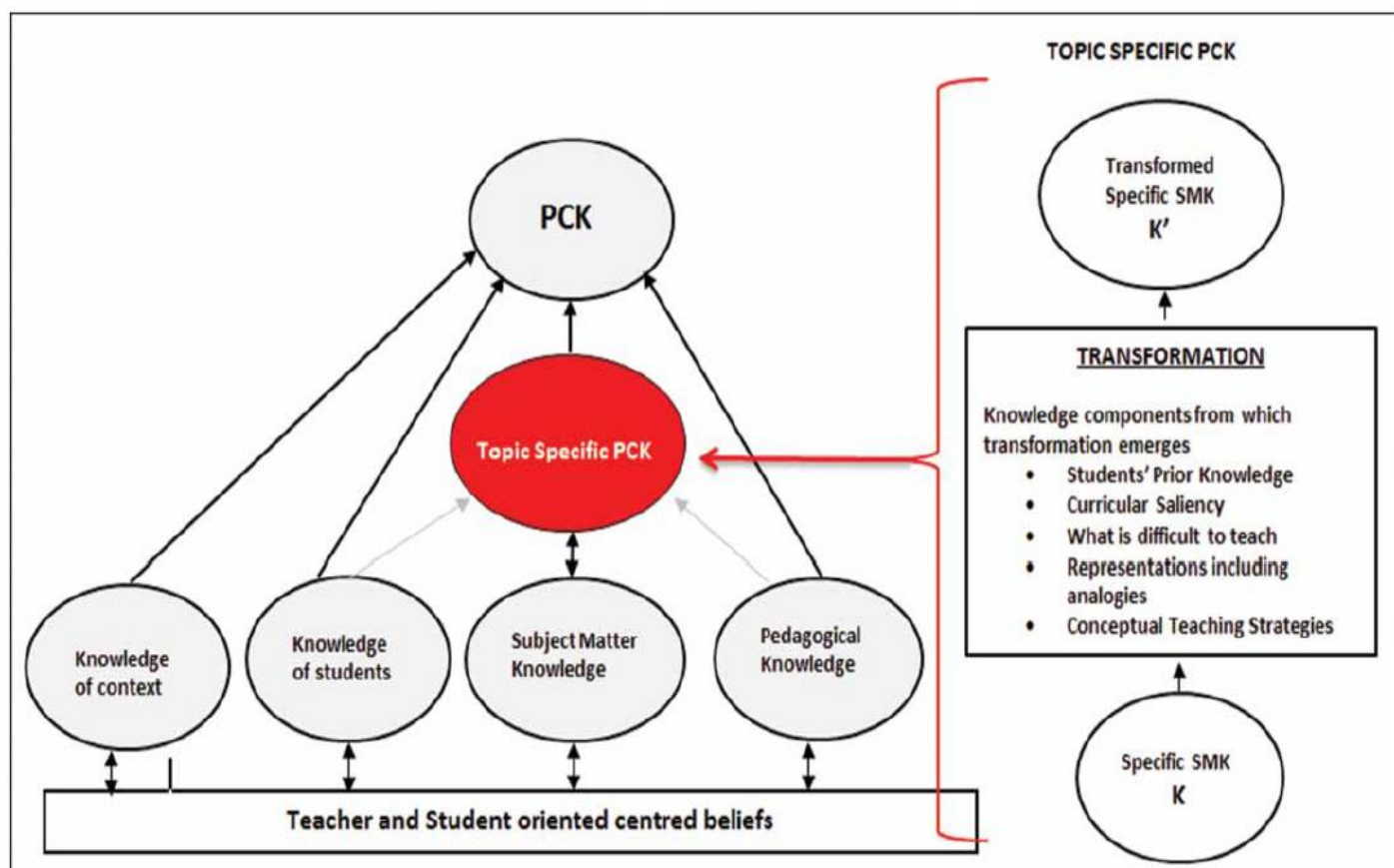


Figure 2.3: TSPCK theoretical framework (Mavhunga and Rollnick, 2013, p. 115)

The theoretical framework of TSPCK is distinct from generic or subject-specific PCK models in that TSPCK can only be defined within a specific topic in science. It is important to my study that Mavhunga and Rollnick showed that it was possible to increase PCK within the topic of Chemical Equilibrium through an intervention with pre-service student teachers in 2013. Content of the topic of Chemical Equilibrium was explicitly engaged with using the TSPCK theoretical framework, in order to transform CK for teaching purposes (Mavhunga and Rollnick, 2013).

2.6 CHOICE OF THEORETICAL FRAMEWORK FOR THIS STUDY

As my study occurs in year 2 of a larger study, I need to use the same theoretical framework that was used in year 1, namely Topic-Specific PCK (TSPCK). In my study I need to assess the quality of TSPCK developed in specific chemistry topics, and determine whether the skill to pedagogically transform CK in one chemistry topic can be transferred to a new chemistry topic. Moreover, if such transfer is observed, I have to determine a viable mechanism for transfer. Since transformation of CK is key in determining the development of TSPCK in the science topics in my study, the TSPCK model as a theoretical framework becomes more relevant for how transformation is defined. CK can be transformed for teaching purposes in this study by engaging with the 5 components of the TSPCK framework. Therefore, I will use the TSPCK theoretical framework for my study.

2.7 LEARNER DIFFICULTIES IN THE TOPICS OF INTERVENTION (ELECTROCHEMISTRY) AND TRANSFER (ORGANIC CHEMISTRY)

In order to know what the sample of pre-service teachers had to consider when they completed the TSPCK tools for the topics of intervention and transfer, I refer to common learner difficulties in these two chemistry topics. Once I understand what makes these topics difficult to learn and teach, I may gain insight into the thought processes as pre-service teachers engaged with the TSPCK components, especially learner prior knowledge. Ndlovu (2013) completed her Masters research study in constructing the TSPCK tool used to measure the quality of TSPCK in the topic of Electrochemistry in 2013 at Wits University.

On a national level it has been shown that questions related to Electrochemistry have been poorly answered in the Grade 12 final science examination papers of 2011 and 2012 (<http://www.education.gov.za>). One of the reasons why this topic might be experienced as being challenging relates to its abstract nature and numerous learner misconceptions. For example, a common misconception relates to the function of the salt bridge in a galvanic cell where students believe that electrons move through the salt bridge in order to complete the circuit. Another example is that students think that water cannot play a part in the electrolysis of aqueous solutions (Garnett and Treagust, 1992). Hamza and Wickman (2007) found that students did not understand chemical processes that occur at the electrodes of electrochemical cells.

The sources of such misconceptions in Electrochemistry have been shown to originate from an inability to link prior concepts with the topic (Geddes and Woods, 1997), incorrect use of terminology and incorrectly applying rules related to the topic (Sanger and Greenbowe, 1997). For the topic of Organic Chemistry, I referred to the research project by Vokwana (2013). She designed and constructed the TSPCK tool for measuring TSPCK in the topic of Organic Chemistry. It has been found by researchers that the topic of Organic Chemistry can be challenging for students (Davidowitz and Rollnick, 2011). A reason for this might be that in textbooks two dimensional structures are meant to represent three dimensional organic molecules. In addition, various types of specific chemical reactions need to be understood in detail, where this is not required in other chemistry topics at school level (Hassan, Hill, and Reid, 2004).

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

In this chapter I describe the research methodology for my study. Firstly, I will elaborate on the research method chosen for my study and explain why it best suits this study. I will then explain the reasons for my choice of research strategy and continue by explaining the reason for the sample of pre-service teachers chosen. I will also discuss the intervention that took place with the sample of pre-service teachers in year 1 of the longitudinal study and refer to the data collection instruments that were used.

3.2 RESEARCH DESIGN

3.2.1 Research method

Though PCK has been perceived by many as a prominent knowledge base from which teachers draw when teaching specific topics, the nature of this knowledge has been described as tacit, making it difficult to capture and portray (Loughran, Mulhall and Berry, 2004). Mavhunga and Rollnick (2013) noted that implementation of PCK at pre-service level has correspondingly remained tacit. Therefore, if an experienced teacher is asked why s/he taught a lesson on Electrochemistry in a particular way, the teacher might not be able to articulate such reasons; perhaps assuming that such reasons are obvious.

This may be because the teacher believes that reasoning about CK for purposes of teaching is based on common-sense knowledge gained from experience. In order to ensure that PCK can be measured at pre-service level, a Mixed Methods approach was selected. Mixed Methods allows for both quantitative and qualitative data to be collected (Teddlie and Tashakkori, 2009) and therefore addresses the weaknesses of both qualitative and quantitative studies. A disadvantage of quantitative studies that is commonly recognised is the influence of contextual factors on the data collected that is often overlooked. This which may result in researcher bias not being identified (Creswell and Plano Clark, 2011). Qualitative research does not have this specific

weakness, but also has limitations. For example, during qualitative studies the researcher can become the data collecting “instrument” and if bias is present during data collection, how will the researcher be aware of subjective interpretations?

Therefore, Mixed Methods approach may be a more suitable research method for social studies as this approach is not limited to use in either quantitative or qualitative studies. This enables a researcher to compare results from a data capturing tool that collected quantitative data, to a tool that collected qualitative data (Creswell and Plano Clark, 2011). Mixed Methods approach is a pragmatic research method that frees the researcher to utilise various methods for data collection as a multiple paradigm of the world is accepted. Pedagogically transforming CK using the TSPCK framework is a process that is not yet fully understood. Therefore, utilising a Mixed Methods approach may increase confidence in the findings as multiple methods can allow for triangulation of data.

3.2.2 Research strategy

One of the purposes of this study is to ascertain whether transference of learnt reasoning occurred from the topic of intervention, Electrochemistry, to the topic of transfer, Organic Chemistry. What is meant by “learnt reasoning” is an acquired skill which enables transformation of topic specific content into a form that is accessible to learners. The aforementioned process is achieved using the five TSPCK components as a means of reasoning about teaching specific content. For example, thinking about learner misconceptions related specific content might inform effective teaching of such content. It was decided that the research strategy would be that of a case study. Opie (2004, p. 74) describes a case study as a “... *in-depth study of interactions of a single instance in an enclosed system*”. I reason that in order research the TSPCK of a small sample of pre-service teachers in two chemistry topics, a case study is justified. The chosen sample of Physical Science BEd pre-service teachers, explained in detail below, justifies a case study because they formed an enclosed system. These pre-service teachers have been together since their first year of study, and met together for lectures on a regular basis during four years of BEd studies. They were bound together at the beginning and during the treatment of this longitudinal study by the requirements of the programme. The sample of pre-service teachers were collectively

exposed to a particular experience and subjected to a particular set of measurements. Therefore, according to Opie (2004, p. 74) considering the group as a particular case justifies my research strategy as a case study.

3.3 SAMPLE

As my study is part of a longitudinal research study that started in the year 2013, the sample and the intervention described below were conducted by a separate researcher in year 1 of the larger study. My study that took place in year 2 started in 2014 by acknowledging the existing data, and extended the study by collecting supplementary qualitative data and the full analysis for possible answers to my research questions. The sample consists of sixteen previous pre-service teachers that were registered for fourth year BEd studies at Wits University in 2013. In 2013, six months before I started my study in 2014, this cohort of pre-service teachers completed TSPCK tools for the topics of intervention and transfer. Currently, some of this cohort has now completed honours studies and is about to start with MSc studies in chemistry education. Others have already started their teaching careers at schools in the Gauteng province. Most of the candidates from this cohort come from a disadvantaged background.

3.4 INTERVENTION

During fourth year BEd studies, the aforementioned cohort of sixteen pre-service teachers was assisted to develop TSPCK for the topic of Electrochemistry in a six week intervention during a methodology course on PCK. Each week during the intervention, pre-service teachers had two sessions lasting roughly one hundred minutes each. During the first session students were introduced to the theory of Constructivism and how it relates to PCK. Though Constructivism is a theory of learning, it entails learner prior knowledge which is a component of TSPCK. It is helpful to know how learning takes place as this may inform teaching practice. During the six week intervention each of the five TSPCK components were discussed explicitly in terms of its usefulness for pedagogically transforming CK for the topic of Electrochemistry. Table 3.1 shows a week-by-week breakdown of what occurred during the intervention.

Table 3.1 Breakdown of what occurred during the intervention (Personal communication with Dr. Elizabeth Mavhunga, 26th July 2015)

Component	Intervention	Specific concepts of CK used
Learners' prior knowledge (week 1)	Discussions were on widely researched common misconceptions on the topic found in the literature. Participants were also encouraged to identify misconceptions that they know. Discussions were followed by a presentation of recommended teaching strategies to correct misconceptions. Where a strategy naturally draws on other components such as representations, such moments would be explicitly highlighted. Links to the learning theory of constructivism was made for this component.	Cathode and anode electrodes Polarity of the electrodes Balancing of the electrochemical cells (galvanic and electrochemical)
Curricular saliency (week 2)	Discussions were geared towards identifying the ' <i>Big Ideas</i> ' and the corresponding subordinate concepts in a topic. The thinking of 'big ideas' is derived from Loughran, Berry and Mulhall (2006) where key concepts in a topic are expressed as statements reflecting their meaning. This was followed by a discussion on sequencing the identified big ideas for scaffolding learning; awareness of the foregrounding concepts needed prior to teaching the Big Idea and knowing what is most important to understand in the big idea.	Big ideas centred on: - Generation vs usage of electricity by the different electrochemical cells - Oxidation- reduction reactions - Disturbance of chemical equilibrium Prior knowledge needed was identified as: - Meaning of oxidation and reduction - Meaning of charge neutrality
What is difficult to teach (week 3)	Exploration of concepts considered difficult to learn, and identifying the actual issues that make understanding difficult. This was more than settling on the abstractness of concepts but pin-pointing the actual difficulty, for example the forward and reverse reactions that are happening at the same time.	Generation of electricity in galvanic cells Difference of polarity of the electrodes in the different electrochemical cells
Knowledge of representations (week 4)	Introduction of the three levels of explanations in chemistry at macroscopic, symbolic and sub-microscopic level. Emphasis was placed in the power of using all three representations side by side in explaining a phenomenon.	Representations of components of electrochemical cells. Representation of the sub-microscopic movement of electrons and ions.
Conceptual Teaching strategies (week 5)	Emphasis was placed on conceptual teaching strategies rather than general pedagogy and logistics. A conceptual teaching strategy would consider the generated knowledge from the other four components.	Misconceptions identified above used as stimuli and conceptual considerations made for curricular saliency, what is difficult and representations pulled to work together in formulating explanations that tackle the misconceptions.
Pulling it together (week 6)	Introduction of Content Representations (CoRe) as a tool to capture thoughts as one thinks about content knowledge of a topic through the knowledge components of TSPCK. The prompts of the original Core were modified to highlight correspondence to the five set of components as discussed in the intervention.	The Big Ideas selected were based on the concepts of Electrochemistry listed above in the component of curricular saliency

Students were assisted to relate each component of TSPCK to different aspects of the topic Electrochemistry. Before each session, students had pre-lesson reading tasks that related to aspects of Electrochemistry and the specific component of TSPCK for that week. Students had to hand in assignments during the six week intervention in order for their progress to be monitored. If it was identified that students had inadequate levels of relevant CK, this would be ameliorated by teaching content accordingly. Near the end of the intervention, CoRes were introduced to the students as a way of capturing PCK through a number of prompts (Loughran, Mulhall and Berry, 2004). The CoRes were adapted to include components of TSPCK. It was possible to capture reasoning from the students on each of the components of TSPCK as it related to the topic of Electrochemistry onto a single plane. The final session concluded with an emphasis on the transformation of CK for teaching purposes that occurred during the intervention.

3.5 UNDERSTANDING THE TSPCK TOOLS USED AND DATA COLLECTION IN YEAR 1 OF THE LONGITUDINAL STUDY

The pre-service teachers completed the TSPCK tool for the topic of intervention (Electrochemistry) directly after completion of the intervention. About three weeks after this the TSPCK tool for topic of transfer was completed in the form of an examination equivalent. All these measurements happened in year 1 of the larger study, prior to my study. It was therefore important to me, at the start of my study in year 2, to establish the validity of the choice of tools used and the rationale prior to engaging with the collected data. This helped me to establish the kind of data needed to answer all of my research questions, in particular the question on establishing mechanism of transfer as it is key to my study. In the discussion below I therefore start by communicating my understanding about TSPCK tools and the process I followed to satisfy myself of the adequacy of the tools used in collecting data in year 1.

It is my understanding that the choice of a data capturing tool should be directly related to the theoretical construct. In order for a tool to be able to provide data that will allow a researcher to answer research questions, there needs to be an epistemological coherence between the theoretical framework and data capturing tool. By this I mean that the data capturing tool needs to be able to reveal the quality of TSPCK according

to the theoretical framework of TSPCK. One of the problems with previously designed data capturing tools is that researchers have not yet come to agree on the exact nature of PCK, or how it can be defined (Park, Jang, Chen and Jung, 2010). The various transformative and integrative PCK models attest to this (Kind, 2009). Therefore, diverse models of PCK used as a theoretical framework for research might result in diverse data capturing tools. Whether data reveals PCK or not will strongly be influenced by the choice of PCK model used as a theoretical framework. Among tools that have been designed to capture PCK, few have been devised to assess the quality of PCK within a specific topic (Mavhunga and Rollnick, 2011). Mavhunga and Rollnick (2013) designed the TSPCK theoretical framework in order to research PCK within specific science topics, and concomitantly had to design data capturing tools that could be used for such science topics.

Two TSPCK data capturing tools were previously designed and validated to measure TSPCK in the topics of Electrochemistry and Organic Chemistry (Ndlovu, 2013 and Vokwana, 2013). The development of the tool to capture TSPCK in Electrochemistry was the main part of a Master's research project by Ndlovu in 2013. Chapter four of Ndlovu's research project elaborates on how the tool was developed. The consecutive stages followed during the design of the TSPCK tool were; "*Conceptualization of test items, construction of the tool and judgment of items, piloting and construction of the actual tool and finally, validation of the instrument*" (Ndlovu, 2013, p. 49). The same procedure was followed for the construction of the Organic Chemistry TSPCK tool by Vokwana (2013).

I noticed that the structure of the aforementioned two TSPCK instruments correlates with the five components of the TSPCK theoretical framework. One of the main considerations during the design of the TSPCK instruments was to ensure that TSPCK quality was measured and not CK. In order to show that CK was not assessed per se, an example is given in Figure 3.1 of a test item related to the learner prior knowledge component of TSPCK. Questions in this test item were related to a topic-specific learner misconception which asked the candidate to confront the misconception with a suitable explanation.

2. What will your answer be to a learner who asks:
"Is it true that in both electrolytic and galvanic cells, oxidation always occurs at the anode and reduction always occurs at the cathode?"

Response A: Yes, it is true that in both electrolytic and galvanic cells, oxidation always occurs at the anode and reduction always occurs at the cathode. The electrons may be lost by the anode material or by the ions near the anode and gained by ions near the cathode.

Response B: Yes, it is true that in both electrolytic and galvanic cells, oxidation always occurs at the anode and reduction at the cathode. The difference is that, in the electrolytic cell the anode is positive while the cathode is negative and vice versa for the galvanic cell. Note that electrons flow from the anode to the cathode.

Response C: Yes, it is true, in both electrolytic and galvanic cells, oxidation always occurs at the anode and reduction at the cathode. However, in the electrolytic cell the cathode has a negative charge and the anode has a positive by virtue of being connected to the positive terminal of the cell.

Response D: None of the above. I have another response, which is...

Figure 3.1: Extract from a test item of the TSPCK tool on learner prior knowledge for topic of intervention - Electrochemistry

A subject specialist may not show evidence of pedagogically transformed CK in an answer provided to this question. Tests were performed to ensure that both TSPCK tools were both valid and reliable. Diagnostic questions for each component assess the quality of TSPCK in Electrochemistry, or Organic Chemistry. Where multiple choice questions are used, additional opportunity for elaboration on the chosen answer is given. Furthermore the tools capture responses that are qualitative in nature, which are scored to generate quantitative values based on qualitative criteria in a TSPCK rubric designed for each TSPCK tool. The TSPCK rubric describes specific competence that could be categorised into four levels of displayed competence. See Figure 3.2 for an extract of the rubric.

TSPCK Components	Limited(1)	(2) Basic	(3) Developing	Exemplary (4)
Category A Learner Prior Knowledge including misconceptions	A1: No identification/No acknowledgement/No consideration of student prior knowledge or misconceptions No explanation of concepts	Teacher only acknowledges misconception/prior knowledge. Provides standardized knowledge as definition Repeats standard concepts/definition with no expansion	Teacher acknowledges misconception and provides explanation to confront misconception that has logic Provide standardized knowledge as definition and/or Expands and re-phrase explanation	Teacher acknowledges misconception and provides a correct explanation to confront misconception Provide standardized knowledge as definition and/or Expands and re-phrases explanation

Figure 3.2: An extract of the TSPCK rubric used in scoring Electrochemistry TSPCK tool (Mavhunga and Rollnick, 2013)

A score of 1 indicated limited TSPCK, 2 basic TSPCK, 3 developing TSPCK and 4 indicated exemplary TSPCK. Differentiation between the categories are by degree. For example, the difference between limited and basic TSPCK, is that with limited there is very little to no evidence of use of a TSPCK component as a framework to reason about teaching specific content, whereas with basic TSPCK there would be some evidence of this. Developing TSPCK needs to show more evidence of using a TSPCK component to reason about teaching specific content than with basic TSPCK. For example, with reference to Figure 3.2, developing TSPCK is differentiated from basic TSPCK with an explanation provided that suitably confronts the misconception allocated. Exemplary TSPCK is differentiated from developing TSPCK by such an aforementioned explanation that is superior. Therefore, differentiation between the four categories shown in Figure 3.2 is by degree in terms of evidence of use of the TSPCK framework to reason about teaching specific content.

In Chapter five of Ndlovu's (2013) research project, she relates how the Electrochemistry tool was validated and checked for reliability. In order for the TSPCK tool to be deemed reliable, TSPCK measured under similar conditions needs to yield similar results. If the tool is deemed valid, it needs to measure what it is intended to measure and not another form of knowledge, for example CK. For validation and reliability studies of both the Electrochemistry and Organic Chemistry TSPCK instruments, the Rasch statistical model was utilised. Rasch scores were seen to corroborate theoretical predictions as to the difficulty of test items. What this meant was that a positive correlation was found to exist between observed and expected performance of respondents. Stated differently, the theorised difficulty of test items corresponded to the calculated difficulty scores (Mavhunga and Rollnick, 2011). Using Rasch scores again, good person and item reliability was determined for both TSPCK tools. The discussion above about the nature of the tools, attempts to provide the rationale that I explored in studying the tools used in capturing TSPCK of the sample in the specific topics. It was important for me to understand their structure and how the tools aligned to my theoretical framework.

This understanding enabled me to start the analysis of the data while looking for evidence towards responses that would assist me in answering my research questions. This level of consciousness was valuable as my study was looking for clues that shed light on the “how” aspects, i.e. how pre-service teachers transfer their learnt reasoning in transforming CK in a new chemistry topic. The analysis for the quality of TSPCK in the respective topics, assisted me to establish whether there was transfer or not. I therefore built on this foundation towards looking for clues to the possible mechanism used. As I was analysing completed tools, a set of questions emerged that were not answered in this analysis. I listed these and formulated an interview schedule that helped me to establish specific clues into the mechanism used (see Appendix E). The interview schedule called for oral discussions with a selection of pre-service teachers from the sample. I describe the process for oral interviews in the section below.

3.6 DATA COLLECTION FOR YEAR 2: MECHANISM OF TRANSFER

While there were questions that emerged during the analysis of the completed tools that are specific to mechanism, certain written responses provided in certain completed tools, also shed light on factors that assisted with the transfer. However, these were insufficient, hence the need for oral interviews. A selection of five pre-service teachers was made based on availability and willingness. Given that there has been a significant elapse of time since the pre-service teachers completed the TSPCK tools, approximately eighteen months, arrangements were made for copies of their completed tool in the topic of transfer (Organic Chemistry) to be sent to them ahead of the oral interviews. The interviews were telephonic, arranged at the time that would suit the candidate. During the interview, the candidates were allowed to refer and read out their responses to specific questions.

3.7 ANALYSIS OF DATA FROM COMPLETED TSPCK TOOLS AND INTERVIEWS

The completed TSPCK tools for both topics of intervention and transfer were scored using specifically designed TSPCK rubrics. This allowed qualitative data from written responses to be converted to quantitative data. This allowed me to perform Rasch statistical analysis on the data which would yield reliability and validity estimates, as

well as a difficulty rank order for test items. The latter may provide insight into a mechanism for transfer of learnt reasoning. Oral interviews were conducted with a selection of available pre-service teachers. The purpose of these interviews was to provide more insight into the findings from the written responses. I was specifically trying to find corroboration for any findings that were drawn from the written responses.

3.8 A SUMMARY OF THE RESEARCH DESIGN USED

I chose to use the Mixed Methods research method. I have justified my choice by explaining that TSPCK is a tacit construct that is not easily measured. A Mixed Methods approach allowed me to collect both qualitative and quantitative data, and compare such data sets (Creswell and Plano Clark, 2011). In this study I will use the power of statistical analysis and the richness of qualitative data in order to answer my research questions. My chosen research strategy is that of a case study. The reason for my choice is based on the sample of 16 pre-service teachers that have formed an enclosed system. Following a six week intervention, this cohort of pre-service teachers completed a TSPCK tool on the topic of Electrochemistry, and afterwards completed a TSPCK tool on the topic of Organic Chemistry. Written responses were scored using specifically design TSPCK rubrics. The latter converted qualitative data from the written responses to quantitative data ready for statistical analysis. Oral interviews were performed in order to give more insight into findings from the written responses.

3.9 ISSUES OF VALIDITY AND RELIABILITY

In order to improve the validity and reliability of any findings drawn from data in this study, I used raters in order to avoid bias. Selected raters had to be active in the field of PCK research. A high level of agreement on scoring a sample of completed TSPCK tools improves reliability of qualitative findings. I therefore used Cohen's Kappa coefficient to establish interrater agreement. The coefficient is a measure of reliability in scoring of the completed TSPCK tools, and so increases reliability for this study. In scoring completed TSPCK tools using specific TSPCK rubrics, qualitative data was converted into quantitative data. In order to measure validity and reliability of quantitative data, Rasch statistical analysis was performed on data from the topics of intervention and transfer. This allowed me to measure the validity and reliability of the

data. Acceptable reliability indicates that should the TSPCK tools used be given to a similar sample, similar performance can be expected. Acceptable validity indicates that TSPCK tools measured TSPCK, and not another type of knowledge such as CK. I could not determine validity or reliability of the interview responses, as interviews were telephonic and hence not recorded. Findings from the interviews were only considered if they were supplementary to existing findings from analysis of written responses.

3.10 ETHICAL CONSIDERATIONS

Pre-service teacher names have been codified in order to protect their identity. Hard copies of completed TSPCK tools were locked away in an office at Wits University. Electronic copies of completed TSPCK tools were password protected. All oral interviews were voluntary.

CHAPTER 4

DATA ANALYSIS FOR TOPIC OF INTERVENTION

4.1 INTRODUCTION

In the previous chapter, I discussed the research design of my study, which took place during the second year of a longitudinal study. In this chapter I discuss the analysis of data gathered to measure the quality of Topic-specific Pedagogical Content Knowledge (TSPCK) in the topic of intervention - Electrochemistry. The data comprises written responses captured using a TSPCK tool for Electrochemistry. I conclude the chapter by summarizing findings from the analysis. This chapter formulates a response to the first part of research question 1: To what extent is TSPCK developed in the topic of intervention and that of transfer?

4.2 MEASURING TSPCK IN ELECTROCHEMISTRY

As referred to in Chapter three, a specially designed TSPCK tool was used to measure the quality of TSPCK in the topic of intervention (Electrochemistry). This TSPCK tool was designed by Ndlovu (2013) as part of a Masters project in 2013 at Wits University. The TSPCK tool comprises five test items, each related to one of the five components of the TSPCK theoretical framework. The test items are in the form of teacher tasks. Shown in Figure 4.1 is an extract of a test item related to the TSPCK component of learner prior knowledge.

CATEGORY A: LEARNERS' PRIOR KNOWLEDGE

1. How do you respond verbally to a learner who writes on a script:

"The electrons flow through the salt bridge to keep the galvanic cell neutral"

Response A: No, this is not the case; the electrons do not flow through the salt bridge to keep the galvanic cell neutral but through the external circuit. Only ions flow through the salt bridge.

Response B: No, this is not the case; electrons need a medium like a wire (solid) which is a good conductor for them to flow. The salt bridge contains a solution and only ions can flow within the salt bridge.

Response C: No, this is not the case; electrons flow through the external wire whereas the ions flow through the salt bridge. The flow of the ions through the salt bridge will maintain the galvanic cell electrically neutral.

Response D: None of the above. I have another response, which is...

Figure 4.1: Another extract from a test item of the Electrochemistry TSPCK tool related to learner prior knowledge

The TSPCK tool for the topic of intervention was administered in the first year of the longitudinal study by the principal investigator. It was completed by the cohort of sixteen pre-service teachers at the end of the six week intervention in the presence of the principal investigator who administering the test. The time taken by the pre-service teachers to complete the pre-test was approximately sixty minutes. The completed tools were first electronically scanned to preserve their integrity. The hardcopies were assigned codes instead of the original names of the participants. Before using the TSPCK rubric to score all sixteen completed TSPCK tools, I first scored a sample of three completed tools, and discussed the results with my supervisor. It was important that my scoring of completed TSPCK tools was consistent.

I attended a workshop in order to discuss rules that would be used during scoring. For example it had to be decided which concepts would constitute Big Ideas for the topic of Electrochemistry as one of test items in the TSPCK tool asked that three Big Ideas be selected from a list of concepts related to the topic. Attendance of the workshop helped me decide which concepts would be accepted as Big Ideas. This helped me to avoid researcher bias when scoring the completed TSPCK tools. In order to increase

validity of scoring two raters were used to score $\pm 20\%$ of the sample. Both these raters are active in researching PCK. In order to ascertain interrater agreement, Cohen's Kappa coefficient was calculated. From (<https://explorable.com/cohens-kappa>): "*Cohen's Kappa is an index that measures interrater agreement for categorical (qualitative) items*". Cohens Kappa coefficient can only be calculated for two raters. Maximum agreement was achieved between the two raters with a Kappa coefficient of 1. This means that two raters scored three completed TSPCK tools for the topic of intervention similarly. Below in Figure 4.2 is an extract from the rubric that was used to score completed TSPCK tools for the topic of intervention.

TSPCK Components	Limited(1)	(2) Basic	(3) Developing	Exemplary (4)
Category A Learner Prior Knowledge including misconceptions	A1: No identification/No acknowledgement/No consideration of student prior knowledge or misconceptions No explanation of concepts	Teacher only acknowledges misconception/prior knowledge. Provides standardized knowledge as definition Repeats standard concepts/definition with no expansion	Teacher acknowledges misconception and provides explanation to confront misconception that has logic Provide standardized knowledge as definition and/or Expands and re-phrase explanation	Teacher acknowledges misconception and provides a correct explanation to confront misconception Provide standardized knowledge as definition and/or Expands and re-phrases explanation
	A2: No identification/No acknowledgement/No consideration of student prior knowledge or misconceptions No explanation of concepts	Teacher only acknowledges misconception/prior knowledge. Provides standardized knowledge as definition Repeats standard concepts/definition with no expansion	Teacher acknowledges misconception and provides explanation to confront misconception that has logic Provide standardized knowledge as definition and/or Expands and re-phrase explanation	Teacher acknowledges misconception and provides a correct explanation to confront misconception Provide standardized knowledge as definition and/or Expands and re-phrases explanation

Figure 4.2: Extract from the TSPCK rubric for the topic of intervention

The TSPCK rubric for the topic of intervention was originally designed by Mavhunga (2012) and further refined in a study by Ndlovu (2013). The nature of the test items was such that it required qualitative responses. Such qualitative data required a TSPCK rubric that would allow me to identify the quality of TSPCK present. The rubric allowed me to give scores from 1 (limited), 2 (basic), 3 (developing) and 4 (exemplary) which showed the quality of TSPCK present in the completed TSPCK tools.

The aforementioned four categories in the TSPCK rubric contain criteria describing a particular quality of response to test items. For example, a weak response might be allocated a score of 1. This kind of score describes a response that has no explanations or expansions on the concept from a particular test item. On the other hand a response that would obtain a score of 4 would reflect both understanding of the knowledge of the component and how it is used to pedagogically transform CK.

If a particular test item in the questionnaire was in multiple choice format it was requested that the pre-service teachers explain their choice of answer. All options for such a test item were essentially correct answers as can be seen in Figure 4.1. Therefore, scoring a response to a multiple choice test item is determined by the explanation given for the choice answer. TSPCK and PCK in general are known to be tacit constructs. Therefore, qualitative data from the completed TSPCK tools provided richer data that provides greater insight as to the ability of candidates to pedagogically transform their CK. The qualitative rubric generated quantitative scores profiling each pre-service teacher in the sample in terms of the quality of TSPCK observed (see example in Table 4.1). An average score for each participant reflected the overall category of quality of TSPCK for the individual.

Table 4.1: Example of quantitative profile obtained with TSPCK rubric – topic of intervention

	Learner prior knowledge	Curricular Saliency	What is difficult	Represent ations	Teacher strategies
TSPCK rubric score	4	2	3	4	3

In Table 4.1 above, a pre-service teacher would have a quantitative TSPCK profile that is exemplary in terms of learner prior knowledge; basic in terms of curricular saliency; developing in “what is difficult”; exemplary in terms of representations and developing in teacher strategies in the topic of Electrochemistry. This profile would not necessarily be similar in other chemistry topics as TSPCK by definition is topic-specific and the construct defined to describe the topic-specificity of PCK. Aydin (2012), as part of doctoral research, found that PCK for two chemistry topics were dissimilar, which confirms the choice of TSPCK as a theoretical framework for this study as it entails two different chemistry topics.

4.3 QUANTITATIVE PROFILES FOR THE SAMPLE

For the sixteen pre-service teachers in the cohort for this study, quantitative TSPCK profiles were found to be as illustrated in Table 4.2.

Table 4.2: Quantitative profile for the sample in the topic of intervention

Topic of intervention - Electrochemistry						
Pre-service teacher	Learner prior knowledge	Curricular saliency	What is difficult	Representations	Teacher strategies	Person average
JN	4	4	2	4	3	3
ANM	4	3	3	3	3	3
BG	3	3	2	3	3	3
LVM	3	2	3	2	3	3
IM	3	2	3	4	3	3
KS	3	3	3	4	3	3
QM	4	3	3	4	4	4
MBN	2	3	2	3	3	3
TS	2	3	3	2	3	3
NCR	2	3	2	3	1	2
TLG	2	3	2	2	1	2
MMJ	2	3	2	2	1	2
DG	2	2	2	2	2	2
VK	2	2	1	2	1	2
SA	1	2	2	2	1	2
XN	1	2	2	2	1	2
Average						3

The average TSPCK rubric score for the topic of intervention is 3. This means this cohort of sixteen pre-service teachers have a developing level of TSPCK for the topic of Electrochemistry. Using the TSPCK rubric as a reference for the quality of TSPCK observed means that when the average pre-service teacher from this cohort engaged with the component of learner prior knowledge, they could acknowledge a learner misconception and provide a logical explanation which may have included a standardised definition and an explanation of it. They could further identify at least two Big Ideas, and order them in a justified logical sequence for teaching purposes. When prompted to construct a concept map for the topic of Electrochemistry, they could link subordinate ideas with Big Ideas and identify concepts that need to be understood prior to learning the topic of Electrochemistry. The cohort could reflect on application of the topic in everyday life experience.

When it came to the “what is difficult” component, they could identify concepts that were related to learner misconceptions or prior knowledge. When pre-service teachers engaged with the component of representations, they could clearly explain how a chosen representation would be used for teaching a particular concept. Lastly, the average pre-service teacher of this cohort engaged with the TSPCK component of teacher strategies by considering learner misconceptions while recognising at least one aspect of curricular saliency, and suggested that two different levels of representation be used for teaching purposes that reflected a conceptual orientation.

4.4 ANALYSIS WITH THE RASCH STATISTICAL MODEL

The generated scores in Table 4.2 were translated into person ability measures using Rasch statistical model, Winsteps, version 3.81.0. One of the reasons why raw score data was converted into Rasch probability measures, is because linearity of raw score data cannot be assumed. For example, if the difficulty level of test items is not equidistant from each other in terms of difficulty, then a score of 2 out of 4 for the Electrochemistry TSPCK tool will not indicate half the ability of a participant who obtained a score of 4 out of 4. Rasch statistical analysis takes into account the assumption of linearity which allows for a more accurate portrayal of learner ability and item difficulty (Boone and Rogan, 2005, p. 27).

Statistical analysis allowed me to determine validity, as well as test item and person reliability measures. If the test item reliability measure is greater than 0.5 (up to a maximum of 1) this means that test items were distinct from one another in terms of difficulty which is an indication that the data capturing tool is reliable (Bond and Fox, 2011). A person reliability measure of 0.5 or higher (up to a maximum of 1) indicates that the sample shows a range of abilities, which increases the reliability of the sample (Bond and Fox, 2011). Acceptable validity of the TSPCK tool is shown if both person and item measures fall within a statistical range of -2 and +2. If this is achieved, then the level of coherence in reliability measures for both persons and items is acceptable (Ndlovu, 2013).

Reliability and validity measures can be summarised on a “bubble chart” generated from Rasch statistical analysis. A bubble chart is helpful in that problematic persons or items can easily be identified. On the bubble chart shown in Figure 4.3 below, the Y-axis represents the difficulty of the test items from the TSPCK tool (smaller circles). The x-axis of the bubble chart is a scale for validity for both test items (small circles) and participants (big circles) with a range of -2 and +2 as referred to earlier.

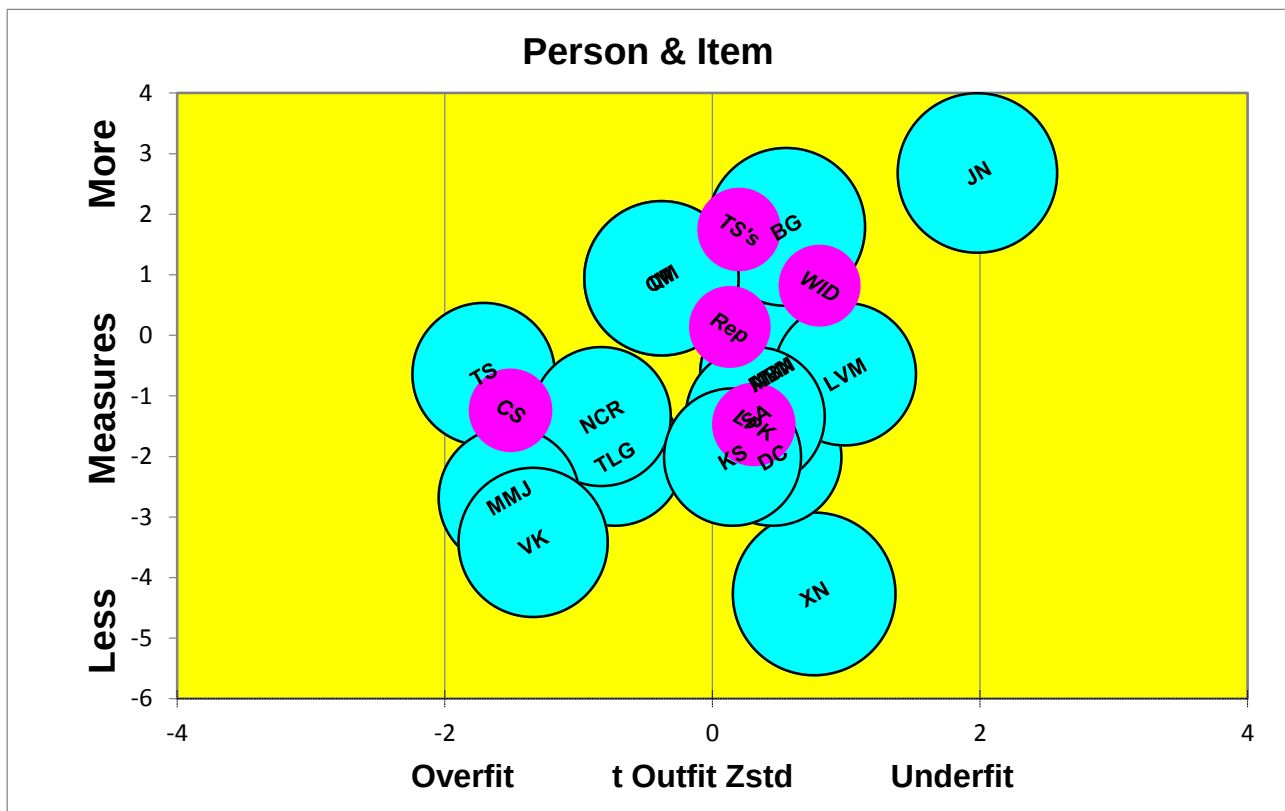


Figure 4.3: Bubble chart for the topic of intervention

As can be seen from the chart above pre-service teachers JN and TS lie on the boundaries of -2 and +2. A possible reason for this might be the small sample size. JN was a pre-service teacher who obtained a very high TSPCK score. As Rasch analyses are sensitive to inconsistencies, it's possible that JN's reliability measure is in dispute as the sample seems to be heterogeneous, containing participants with a range of ability. Therefore, this is still deemed acceptable for a small sample. Test item validity falls within the acceptable range as well. It can be seen that the test items do not overlap. However, looking at test items as they relate to each other on the y-axis, the items were mostly distinct in their difficulty level, but learner prior knowledge and curricular saliency seems to be comparable in terms of how difficult participants found

these test items. Bar this occurrence, it can be interpreted that test items of the Electrochemistry TSPCK tool are experienced as distinct from each other in terms of difficulty to engage with and how they measure TSPCK. A summary of statistics for the topic of intervention is shown in Table 4.3.

Table 4.3: Summary statistics for the topic of intervention

Person reliability	0.77
Item reliability	0.84
Fit statistics	Rasch measures for reliability fell within the range of +2, -2

Rasch statistical analysis places items on a linear scale, which allowed me to compare the rank order of difficulty of test items. Test items of the TSPCK tools are directly related to the five TSPCK components. Therefore, the rank order of difficulty of test items shown in Table 4.4 provides a clear sense of which TSPCK components were most difficult when pre-service teachers engaged with them in order to transform their CK. Knowing the rank order of item difficulty, and concomitantly the rank order of difficulty for engagement with TSPCK components, is helpful as it may provide insight to a possible mechanism of how pre-service teachers transfer their learnt reasoning to a new chemistry topic.

Table 4.4: Rank order difficulty for topic of intervention

Rank order	Questionnaire Items	Item Rasch measures
1	Teacher strategies	1.75
2	What is difficult	0.82
3	Representations	0.14
4	Curricular saliency	-1.24
5	Learner prior knowledge	-1.47

From Table 4.4 the greatest positive item measure represents the TSPCK component which the pre-service teachers found most difficult to engage with. Therefore, within the topic of intervention, teacher strategies was the most difficult TSPCK component. This might be because teacher strategies involve engagement with various components of TSPCK. Learner prior knowledge, on the other hand, was the easiest TSPCK component engaged with. The analysis, therefore, has established the quality of TSPCK in the topic of intervention and further has shown acceptable reliability and validity. It is also important to demonstrate the nature of the quality of qualitative responses that demonstrates the developing quality of TSPCK for the sample.

4.5 EXAMPLE OF PERCEIVED ABILITY TO TRANSFORM CK

In order to show how the TSPCK tool for the topic of intervention captured evidence of pedagogical transformation of CK, I will provide an extract from the completed tools. It is mentioned that such extracts cannot provide evidence of TSPCK per se, as TSPCK by definition can only be observed if CK is transformed using all five of the TSPCK components. In Figure 4.4 below an extract from the test item related to the TSPCK component of learner prior knowledge is given. It relates to a learner misconception that electrons flow through a salt bridge in a galvanic cell in order to close the circuit.

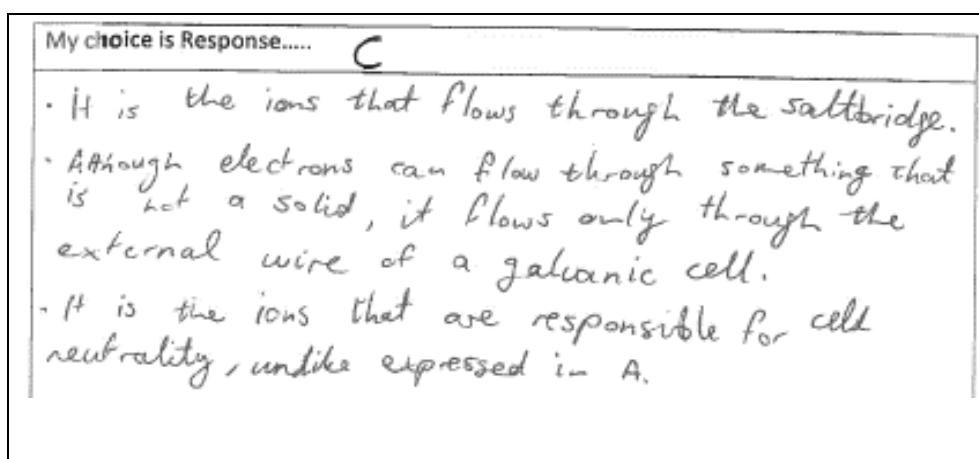


Figure 4.4: Extract of engagement with learner prior knowledge for QM – topic of intervention

It is commonly known that a misconception about the purpose of the salt bridge in a galvanic cell is that it allows electrons to flow through it in order to complete the circuit.

Pre-service teacher QM addresses this misconception by confronting it directly in stating that electrons only flow *“through the external wire of a galvanic cell”*. This shows evidence of learner prior knowledge. In addition, QM emphasises that ions are responsible for cell electrical neutrality. This shows evidence of curricular saliency as QM is sequencing what is to be taught in a logical manner. First, the misconception is confronted directly by stating that the salt bridge cannot allow movement of electrons. Secondly, QM provides the correct answer by making reference to the movement of ions through the salt bridge that is responsible for cell electrical neutrality.

4.6 SUMMARISING THE FINDINGS

The cohort of sixteen pre-service teachers underwent a six week intervention during which they were facilitated to engage with their CK in order to pedagogically transform it using the five components of the TSPCK construct. The TSPCK rubric score for the average pre-service teacher of the sample was 3 out of 4 which revealed a developing quality of TSPCK for the topic of intervention. This is impressive as PCK is generally assumed to be present with expert teachers that have many years of experience in their teaching practice. In the next chapter statistical analysis of data from the topic of transfer (Organic Chemistry) will be discussed. With regards to the first research question for this study: To what extent is TSPCK developed in the topic of intervention and that of transfer? I cannot fully answer this question until I have discussed the findings from Chapter five. However, the findings discussed in this chapter indicate that on completion of the intervention the pre-service teachers had a developing quality of TSPCK in Electrochemistry.

CHAPTER 5

DATA ANALYSIS FOR TOPIC OF TRANSFER

5.1 INTRODUCTION

In Chapter four, I discussed the analysis of completed TSPCK tools from the topic of intervention (Electrochemistry). In this chapter I discuss the analysis of completed TSPCK tools for the topic of transfer (Organic Chemistry). The findings from this topic will shed light on the extent of development of TSPCK in the topic of transfer. The structure of Chapter five is similar to that of Chapter four. I conclude the chapter by summarising the findings from the analysis. The chapter formulates a response to both the first research question: To what extent is TSPCK developed in the topic of intervention and that of transfer? And also the second research question: To what extent has transfer of learnt reasoning happened in a new Chemistry topic?

5.2 MEASURING TSPCK IN ORGANIC CHEMISTRY

An Organic Chemistry TSPCK tool was designed by Vokwana (2013). The TSPCK tool was constructed according to the same method used for the Electrochemistry TSPCK tool. As mentioned earlier, the conceptual stages followed in tool construction were conceptualisation of test items, construction of the instrument and judgment of items, piloting and construction of the actual instrument and finally, validation of the instrument (Ndlovu, 2013, p. 49). Each test item is related to a component of the TSPCK construct. In Figure 5.1 an extract of the Organic Chemistry TSPCK tool is given.

Section A: STUDENT'S PRIOR KNOWLEDGE

1. You hand out a worksheet to be used in a classroom activity and ask students to select compounds that are alcohols from the table below:

1 $\text{CH}_3\text{-OH}$	2 $\text{CH}_3\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-OH}$	3 $\text{CH}_3\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-H}$	4 $\text{CH}_3\text{-CH}_2\text{-OH}$
5 $\text{CH}_3\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-CH}_3$	6 $\text{H}\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-O-CH}_3$	7 NaOH	8 $\text{CH}_3\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-O-CH}_3$

Sipho selects compounds 1, 2, 4 and 7. You then realize that other students in the class have given the same response. How would you explain to the students in the class how to distinguish alcohols from other compounds?

Figure 5.1: Extract from a test item of the Organic Chemistry TSPCK tool related to learner prior knowledge

The completed TSPCK tools were again scanned, and hard copies were assigned codes to protect the identity of the pre-service teachers. Cohen's Kappa coefficient for interrater agreement was calculated for the topic of transfer. Approximately 20% of the completed TSPCK tools for the topic of transfer were scored by two raters who are active in the field of PCK research. Once again a Kappa coefficient of 1 was achieved which shows perfect interrater agreement and therefore indicates good reliability in the scoring of completed TSPCK tools for both the topics of intervention and transfer. In Figure 5.2 an extract of the TSPCK rubric for the topic of transfer is shown.

TSPCK Components	(1) Limited	(2) Basic	(3) Developing	(4) Exemplary
Learner Prior Knowledge including misconceptions (may be implied)	- Content-based explanation only (correct answer) - No consideration of student prior knowledge or misconceptions	- Identifies misconception or prior knowledge - Provides standardized knowledge as definition	- Identifies misconception or prior knowledge - Provides standardized knowledge as definition - Expands explanation	- Identifies misconception or prior knowledge - Provides standardized knowledge as definition - Expands explanation - Explanation demonstrates conceptual understanding
Section A1 and A2				

Figure 5.2: Extract from the TSPCK rubric for the topic of transfer

I used the TSPCK rubric for the topic of transfer to measure the quality of TSPCK of the sample of pre-service teachers from written responses. This process was similar to what was done with the written responses for the topic of intervention. The qualitative rubric generated quantitative scores profiling each pre-service teacher in the sample as with the topic of intervention explained in Chapter four.

5.3 QUANTITATIVE PROFILES FOR THE SAMPLE

For the pre-service teachers in this study their quantitative TSPCK profile were found to be as illustrated in Table 5.1 below.

Table 5.1: Quantitative profile for the sample in the topic of transfer

Topic of transfer - Organic Chemistry						
Pre-service teachers	Learner prior knowledge	Curricular saliency	What is difficult	Representations	Teacher strategies	Person average
JN	4	3	2	4	3	3
TS	2	3	3	2	3	3
MBN	2	3	2	3	3	3
ANM	4	3	3	3	3	3
BG	3	3	2	3	3	3
LVM	3	2	3	2	3	3
IM	2	2	3	4	3	3
KS	2	3	3	4	3	3
QM	3	3	3	4	4	3
TLG	2	3	2	2	1	2
NCR	2	3	2	3	1	2
XN	1	2	2	2	1	2
DG	2	2	3	3	2	2
SA	1	2	2	2	1	2
MMJ	2	3	2	2	1	2
VK	2	2	1	2	1	2
Average						3

As can be seen from Table 5.1 the sample of pre-service teachers obtained an average rubric score of 3 out of 4 for topic of transfer. This TSPCK score reveals the same developing quality of TSPCK present in the topic of transfer as compared to the

topic of intervention. For the topic of transfer, this means that the average pre-service teacher when engaging the component of learner prior knowledge, could identify learner misconceptions and confront them using standardised definitions with suitable explanations. With regards to curricular saliency, they could identify four prior concepts and justify this choice by referring to conceptual reasons related to the topic. When it came to identifying Big Ideas, pre-service teachers could identify three Big Ideas and sequence them for teaching in a logical manner. Reasons for the sequencing, however, may lean more on generic aspects. Concept maps drawn by the average pre-service teacher showed Big Ideas connected with subordinate ideas. When candidates engaged with the component “what is difficult”, the average pre-service teacher could identify specific concepts that related to learner prior knowledge. For the component of representations, candidates could explain the use of two examples of representations on multiple levels, i.e. macro and sub-micro. Lastly, when pre-service teachers engaged with the component of teacher strategies, they chose a strategy which showed consideration of common learner misconceptions.

5.4 ANALYSIS WITH THE RASCH STATISTICAL MODEL

Below in Figure 5.3 a bubble chart is shown for data from the topic of transfer.

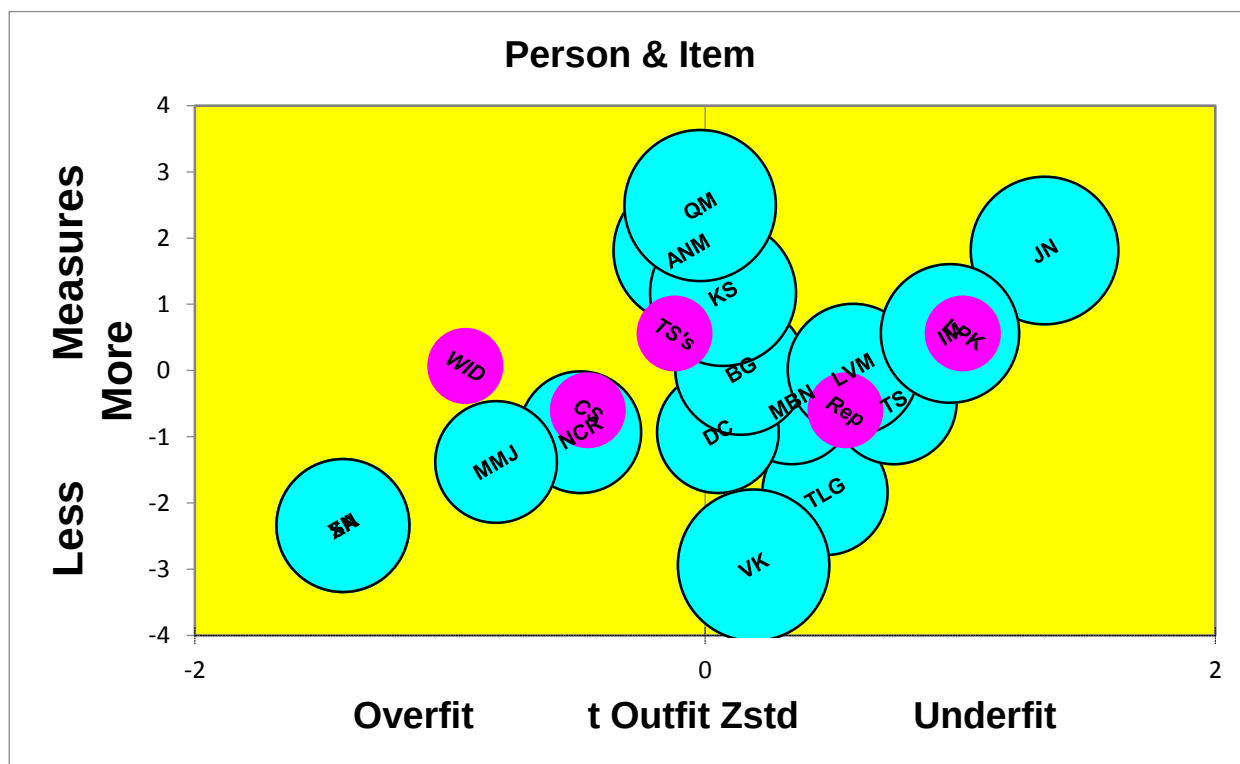


Figure 5.3: Bubble chart for the topic of transfer

It can be seen from Figure 5.3 that all person reliability measures fell within the acceptable range of -2 and +2. As with the topic of intervention, test items do not coincide with each other on the chart, which means that the test items were testing distinct knowledge for teaching Organic Chemistry. From Figure 5.3 it is possible to see that when pre-service teachers engaged with the components of representations and curricular saliency, it was experienced equally difficult as the y-axis shows the difficulty level. This could also be said of the components teacher strategies and learner prior knowledge. This does not indicate good test item reliability, and as can be seen in Table 5.2, item reliability is lower compared to that of the topic of intervention (0.84).

Table 5.2: Summary statistics for the topic of transfer

Person reliability	0.83
Item reliability	0.65
Fit statistics	Rasch measures for reliability fell within the range of +2, -2

However, person and item reliability measures were still above a value of 0.6 indicating acceptable reliability which means that if a similar sample were given the TSPCK tool for the topic of transfer to complete, they would perform comparably to this cohort of pre-service teachers. Rasch probability measures fall within an acceptable range of -2, +2 indicating that the TSPCK tool for the topic of transfer was measuring TSPCK.

As mentioned in Chapter four, a significant additional benefit of Rasch statistical analysis is that rank order difficulty of test items from the TSPCK tool can be determined. The rank order for test item difficulty is shown in Table 5.3. As referred to in Chapter three, because test items of the TSPCK tools are directly related to the five TSPCK components, the rank order of test items allows me to infer a similar rank order for difficulty of engaging with the five TSPCK components. The reason why this data is useful, relates to the investigation of a mechanism that can explain how pre-service teachers transferred an ability to pedagogically transform CK from the topic of intervention to the topic of transfer.

Table 5.3: Rank order difficulty for topic of transfer

Rank order	Questionnaire Items	Item Rasch measures
1	Teacher strategies	0.99
2	Learner prior knowledge	0.53
3	What is difficult	0.31
4	Curricular saliency	-0.58
5	Representations	-1.25

It is interesting to see that teacher strategies was the most difficult TSPCK component engaged with to transform CK in both topics of intervention and transfer. As referred to in Chapter four, a possible reason to explain this phenomenon might be that teacher representations involve the engagement with multiple components simultaneously. This may be more challenging for pre-service teachers. Learner prior knowledge was the second most difficult test item for transformation of CK. In contrast, in the topic of intervention learner prior knowledge was the easiest component engaged with for transformation. This attests to the topic-specificity of PCK. TSPCK enables pedagogical transformation of CK for a specific topic for teaching purposes. This is evidence against the belief that PCK is subject specific or generic in nature.

5.5 EXAMPLE OF PERCEIVED ABILITY TO TRANSFORM CONTENT KNOWLEDGE

Similarly to Chapter four, an extract of a completed TSPCK tool is given as evidence of the ability to transform CK for teaching purposes. In Figure 5.4 an extract is given of a learner misconception that is confronted by pre-service teacher KS. Evidence that KS is engaging with the component of learner prior knowledge in order to transform CK is shown in that KS provides a standard definition of an alcohol as the misconception in this test item is related identification of alcohols. Pre-service teacher KS then elaborates on the use of sub-microscopic and symbolic representations in order to explain how alcohols can be identified for a list of given substances.

*I would first give learners a definition of an alcohol.
 -Alcohol: when a hydroxyl functional group OH is bonded to a carbon atom or one or more hydroxyl groups attached to a carbon atom.
 *So I would further explain that the alcohol is different from other compounds because the -OH is bonded to a carbon atom and NO other functional groups are bonded to that particular carbon atom e.g. -C-OH .
 *And I will further explain that the general formula for alcohols is $\text{C}_n\text{H}_{2n+1}\text{OH}$, where the CH_2OH are present. with regards to other compounds they often contain -OH and other functional groups on the same carbon atom, while alcohols contain -OH only on the carbon atom. And alcohols are defined by the Hydroxyl -OH functional group.

Figure 5.4: Extract of engagement with learner prior knowledge for KS – topic of transfer

This shows interplay between the TSPCK components of learner prior knowledge and representations in reasoning about teaching a specific chemistry topic. If engagement with one TSPCK component involves engagement with other components, it is generally considered as evidence of transformation of CK for the purpose of teaching. For example, in Figure 5.5 an extract of the TSPCK rubric for the topic of transfer is shown. Developing and exemplary TSPCK for the component “what is difficult” requires engagement with another component of TSPCK.

TSPCK Components	(1) Limited	(2) Basic	(3) Developing	(4) Exemplary
What makes topic difficult to teach Section C	- Identifies broad topics without specifying the actual sub-concepts that are problematic - Reasons not given	- Identifies specific concepts - Provides broad /generic reasons such as 'abstract'	Identifies specific concepts with reasons related to prior knowledge of students or common misconceptions (which may be implied)	- Identifies specific concepts with reasons related to prior knowledge of students or common misconceptions - Provides reasons linking to specific gate keeping concept(s) that when not fully understood adds to the difficulty of a concept regarded as difficult

Figure 5.5: Extract of TSPCK rubric for topic of transfer – “what is difficult”

5.6 SUMMARISING THE FINDINGS

The sample of pre-service teachers achieved an average TSPCK rubric score of 3 for the topic of transfer. This score indicates that the average pre-service teacher's TSPCK is of developing quality, according to the TSPCK rubric used (see Appendix D). It was not expected that this cohort of pre-service teachers would show evidence of developing quality TSPCK for the topic of transfer since they were not assisted to engage with the TSPCK components to transform their CK. In addition, the sample of pre-service teachers had very little teaching experience which is generally considered requisite for PCK development. Therefore, it would be unlikely to measure a developing quality of TSPCK for the topic of Organic Chemistry unless there was application of pedagogical reasoning that was learnt during the six week intervention for the topic of Electrochemistry. The findings from this chapter assist in answering two of three research questions of this study. These are:

1. To what extent is TSPCK developed in the topic of intervention and that of transfer?
2. To what extent has transfer of learnt reasoning happened in a new Chemistry topic?

After analysis of the written responses for the topics of intervention and transfer respectively, I can now answer research question 1 in that TSPCK in both topics of intervention and transfer has been developed to the level of developing quality, which is one level below the highest level of exemplary. I have described in the section above the kind of competence denoted by this quality of TSPCK. With regards to research question 2, I can conclude that learnt reasoning was transferred from the topic of intervention to that of transfer to the same extent. The mechanism of this process relates to research question 3 which will be addressed in Chapter six, and discussed in Chapter seven.

CHAPTER 6

THE MECHANISM OF TRANSFER

6.1 INTRODUCTION

In Chapter four TSPCK was measured in the sample of pre-service teachers due to an intervention that explicitly developed pedagogical reasoning skills to transform CK in the topic of Electrochemistry. In Chapter five the transfer of the learnt reasoning into the topic of Organic Chemistry was observed. It was found that the average scores for both topics corresponded to a developing quality level of TSPCK. Despite the small sample, acceptable levels of reliability and validity were calculated using the Rasch statistical model. The performance achieved by pre-service teachers during the topic of transfer indicated that transfer of learnt reasoning did occur. In this chapter, the nature of a possible mechanism that pre-service teachers used to transfer learnt reasoning from the topic of intervention to the topic of transfer is investigated in order to answer the remaining research question of this study.

6.2 SUMMARY OF WHAT HAS BEEN DONE TO THIS POINT

The focus of this chapter is to investigate the mechanism that pre-service teachers used to transfer learnt pedagogical reasoning from the topic of intervention (Electrochemistry) to a new topic (Organic Chemistry). The evidence of the transfer is based on measured TSPCK in the respective topics. Specially designed TSPCK tools, as explained in Chapter three, were used to measure the quality of TSPCK in the topics.

The findings in Chapter five confirm a positive transfer of learnt reasoning, enabling the pre-service teachers to engage with the content of the new topic and develop TSPCK in it. This finding confirms a similar transfer using a similar intervention reported in a study by Mavhunga (2014a) from the topic of particulate nature of matter to the topic of chemical equilibrium. It is however important to note that the TSPCK measured in this study, and that by Mavhunga, is in a context of planning for teaching rather than enactment in teaching practice. According to Park, Jang, Chen and Jung

(2010), both the development of PCK in planning and in enactment contexts are important. In the following discussion I first refer to observations that were made from analysis of completed TSPCK tools for both topics of intervention and transfer. The analysis is then complimented with findings from oral interviews with five pre-service teachers.

6.3 MECHANISM FOR TRANSFER OF LEARNT REASONING

6.3.1 Comparing the rank order of difficulty of items across the two topics

When answering a question about mechanism, one often looks at clues that could explain “what was used” and “how something was done”. In looking for what pre-service teachers could have used as a means for engaging with a new topic from the TSPCK perspective, I first compared the set of completed TSPCK tools from the topic of intervention (Electrochemistry) to the set on the topic of transfer (Organic Chemistry). The comparison was first done by comparing the statistical generated values on the completed tools.

As discussed in Chapters four and five, the raw score generated from using the TSPCK rubric (quantitative profiles) were converted into probability measures using the Rasch statistical model. One of the calculations generated by the Rasch model is a feature called the “test item difficulty rank order”. This feature compares the test items in terms of how difficult participants experienced them. It allows the difficulty of test items to be measured on a linear scale (Boone and Rogan, 2005). This is helpful because both the difficulty of the items and the person abilities to answer them correctly are placed onto the same scale. In the case of the TSPCK tools, the test items were directly related the TSPCK components. Therefore, the calculated rank order for difficulty of test items revealed the rank order of difficulty of engagement with the five TSPCK components. Table 6.1 and 6.2 shows the rank order of difficulty of engagement with the five TSPCK components for the topics of intervention and transfer respectively.

Table 6.1: Rank order of difficulty of TSPCK components engaged (Electrochemistry)

Topic: Electrochemistry	Learner prior knowledge	Curricular saliency	Representations	What is difficult	Conceptual Teaching strategies
Rasch measures for topic of intervention (Electrochemistry)	-1.47	-1.24	0.14	0.82	1.75
Order of difficulty	< (least difficult)	<	<	<	< (most difficult)

Table 6.1 above shows that pre-service teachers in the topic of intervention experienced the TSPCK component of learner prior knowledge as easiest when engaging it for pedagogical transformation of CK. Conceptual teaching strategy was experienced as the most difficult component to engage with. The pattern is different in the topic of transfer (see Table 6.2).

Table 6.2: Rank order of difficulty of TSPCK components engaged (Organic Chemistry)

Topic: Organic Chemistry	Representations	Curricular saliency	What is difficult to understand?	Learner prior knowledge	Conceptual Teaching strategies
Rasch measures for topic of transfer (Organic Chemistry)	-1.25	-0.58	0.31	0.53	0.99
Order of difficulty	< (least difficult)	<	<	<	< (most difficult)

6.3.2 Looking at engagement with representations for the topic of transfer

The rank order difficulty of engagement with TSPCK components for various topics should not be expected to be similar, in that generating TSPCK related to a particular component is unique, as the concept is unique, which requires unique pedagogical considerations. The TSPCK component of representations was experienced by the sample of pre-service teachers as easiest in the topic of transfer. This may be due to the uniqueness of the specific topic of Organic Chemistry. The high scores generated for the TSPCK component of representations, making it the easiest in the rank order as observed, mean that pre-service teachers can select a preferred representation that is specific to the topic of Organic Chemistry and justify their selection from a

teaching perspective. This is different from the general teaching methodology that representations per se are useful in teaching.

In this case of pre-service teachers engaging with representations for transformation of CK in the topic of Organic Chemistry, representations chosen are specific with good conceptual and pedagogical justification. As a result of this finding, the responses in the TSPCK tool for the topic of transfer were re-examined looking for evidence that would support the calculated rank order of difficulty for the component of representations. A particularly interesting finding was that pre-service teachers used representations when engaging with other TSPCK components. Table 6.3 shows cases where representations were used other than in the discussion for the representation component.

Table 6.3: Representations used in other TSPCK components

Pre-service teachers	Learner Prior Knowledge	Teacher Strategies	Curricular Saliency
KV	X		
QM	X		X
MMJ		X	
KS	X	X	
SA		X	X
LVM	X	X	
ANM	X		
NCR	X	X	
TS		X	
XS	X	X	
TLG		X	
JN		X	
MBN			
BG			
IM			
DG			

What can be seen in Table 6.3 is that twelve out of sixteen, or 75% of the sample of pre-service teachers used representations when engaging with other test items related

to learner prior knowledge, curricular saliency and teacher strategies components. Figures 6.1 and 6.2 show extracts of completed TSPCK tools for the topic of transfer for pre-service teachers KS and TLG respectively. These extracts show examples of how most of the pre-service teachers from the sample engaged with the component of representations while engaging with learner prior knowledge and teacher strategies in the topic of transfer.

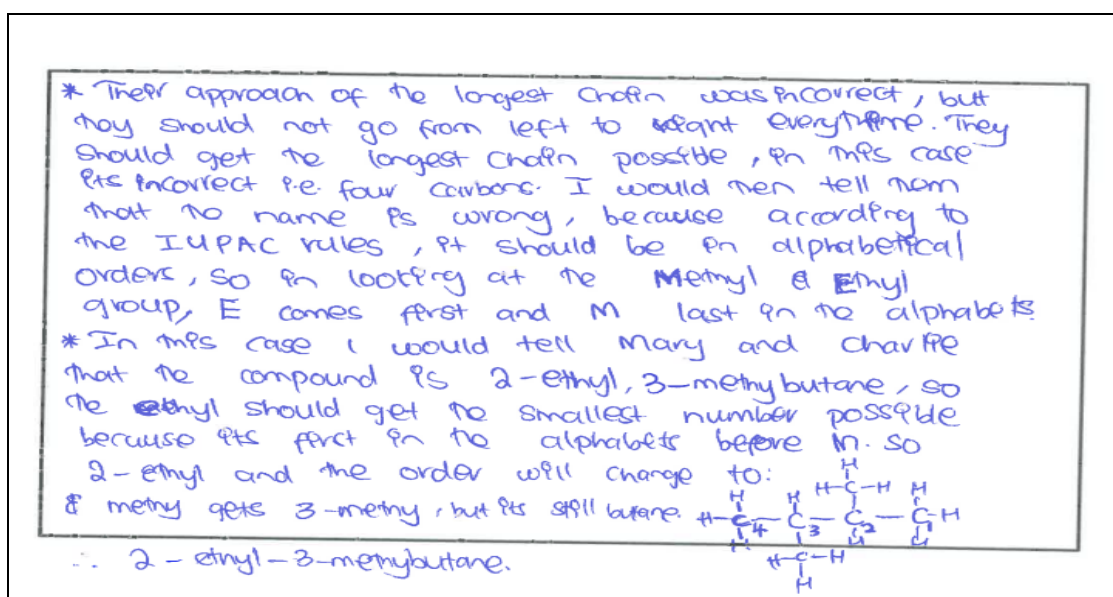


Figure 6.1: An extract showing the use of representations when engaging with learner misconceptions

The extract shown in Figure 6.1 shows KS confronting a learner misconception related to learner prior knowledge and used a representation to support the explanation. This extract supports the argument made earlier that the thinking about representations demonstrated by the pre-service teachers is very specific to the CK of the topic, as argued by Ball, Thames and Phelps (2008), rather than being general. In Figure 6.2 an extract from the written response of pre-service teacher TLG shows utilisation of multiple sub-micro representations as part of a conceptual teacher strategy to explain isomers. The component of teacher strategies was the most difficult to engage with in both topics of intervention and transfer. It is possible that TLG made recourse to representations when engaging with teacher strategies, because it was easier to think of representations.

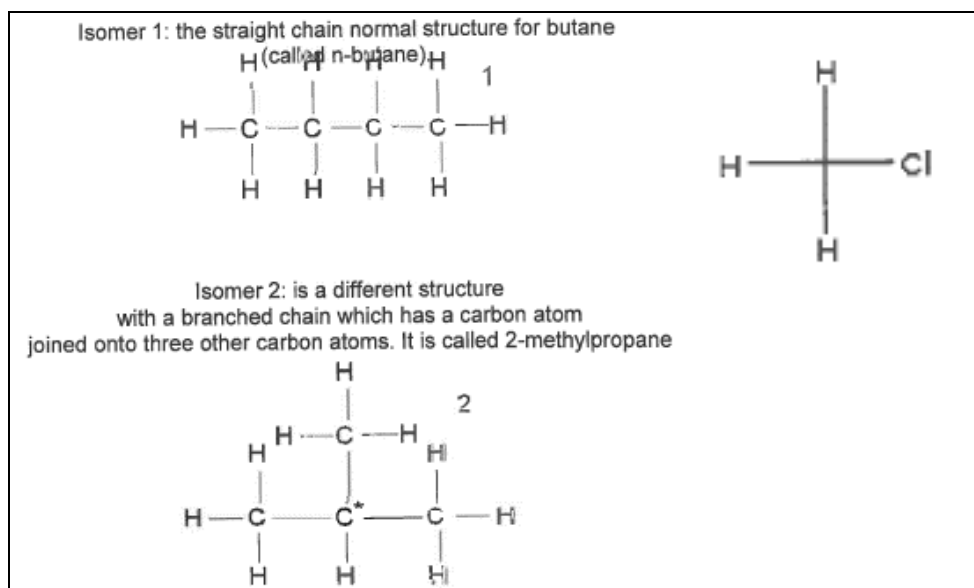


Figure 6.2: An extract showing the use of representations in engaging with teacher strategies

TLG used representations to come up with a teacher strategy. From the extract shown in Figure 6.3, pre-service teacher QM justifies the sequence of Big Ideas for a test item related to curricular saliency by referring to sub-micro representations.

4 Explain briefly your reasons for the order you chose. [1 marks]

It is important to firstly introduce the various methods of representations, as learners will then be able to identify functional groups, regardless of whether the molecule is represented as $\text{CH}_3(\text{CH}_2)_3\text{CH}_2\text{OH}$ OR

$$\begin{array}{ccccccc}
 & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\
 & | & | & | & | & | \\
 \text{H} & - \text{C} & - \text{C} & - \text{C} & - \text{C} & - \text{C} & - \text{OH} \\
 & | & | & | & | & | \\
 & \text{H} & \text{H} & \text{H} & \text{H} & \text{H}
 \end{array}$$

Learners are then taught the different functional groups, and once being able to identify different functional groups, learners will be taught how to use this knowledge to name organic compounds using the IUPAC system

Figure 6.3: An extract showing the use of representations when engaging with the component of curricular saliency

The discussion above point to use of the TSPCK component of representations as recourse to express thoughts generated as pre-service teachers in this study engaged with a new topic. Further analysis of representations used in the written responses revealed different levels of representation, specifically symbolic and sub-microscopic shown in Table 6.4. Treagust, Chittleborough and Mamiala (2003) argue that novices do not have the ability to transfer between different levels of representation. One way to assist such novice students is to make different levels of representation explicit. It is interesting that only three pre-service teachers recommended that both symbolic and sub-microscopic representations be used in order to confront a misconception when they were engaging with teacher strategies. These pre-service teachers namely ANM, TS and JN achieved high scores in the TSPCK tool for the topic of transfer.

Table 6.4: Use of different levels of representations when engaging with teacher strategies

	Modelling clay	Sub-micro representation	Paper model	Computer simulation	Ball and stick model
QM	X				
IM	X				
SA		X			
LVM		X			
BG			X		
ANM		X		X	X
MBN					X
NCR		X			
TS		X		X	
XS		X			
TLG		X			
JN				X	X
KS					
DG					
MMJ					
KV					

It therefore seems that pre-service teachers found representations helpful in order to engage with other TSPCK components. This conclusion is drawn from the written responses that showed that the sample found representations to have been the easiest component to engage with for the topic of transfer. The occurrence of representations in other TSPCK components support this conclusion. The discussion above points to the use of representations as a possible tool that enabled engagement in the new topic towards pedagogical transformation.

6.3.3 Looking at reasons behind the formulation of Big Ideas

The second aspect that seems to have helped the pre-service teachers is substantial CK. I was interested in the reasons that pre-service teachers provided for their sequence of Big Ideas in one of the test items related to curricular saliency. The identification of Big Ideas in itself is a difficult process often done by practising teachers as a group (Loughran, Mulhall, and Berry, 2004). Pre-service teachers had to reflect on their choices in the formulation and sequencing of Big Ideas. It was observed that most pre-service teachers seemed to have drawn from CK in order to provide the sequence. According to Shulman (1987) pedagogical reasoning has several aspects. Firstly, a teacher preparing to teach needs to comprehend and understand the topic and how it relates to other ideas in the subject area. Though it can be said that CK per se does not form a sufficient knowledge base for teaching, it is essential according to Shulman as knowledge for teaching “*lies at the intersection of content and pedagogy*” (1987, p. 15). Therefore, if CK is inadequate teaching quality is compromised. Figure 6.4 shows extracts of written responses for test items related the component of curricular saliency for pre-service teachers ANM (left) and LVM (right).

Carbon has a unique nature.	① Carbon has a unique nature ✓
Functional groups in organic chemistry.	② Organic Compounds are named according to the IUPAC system.
IUPAC naming system.	③ Functional groups in organic chemistry tell us about the different types of compounds.

The nature of carbon is the reason for the vast number of organic molecules.

Organic chemistry is the chemistry of carbon. The functional groups are what makes organic molecules different. They are the reason for the different reactions and most of the properties.

The naming system is linked to the structure. By learning the names, learners simultaneously grasp the structure of molecules.

The learners first have to know that Carbon is the main element that is dealt with in organic chemistry. And that will help them understand that it forms different compounds that make different structures.

Figure 6.4: An extract showing two pre-service teachers' reasoning related to sequencing of Big Ideas (ANM left, LVM right)

Pre-service teacher ANM (achieved an average rubric score of 3 out of 4 for the topic of transfer. Firstly, ANM identified correct Big Ideas and secondly Big Ideas were sequenced appropriately. The latter can be seen by the reason provided for the sequence of Big Ideas. It is logical to teach carbon's unique properties first, because as ANM points out in her reasoning, all concepts in Organic Chemistry relate to carbon and its unique properties. Functional groups are taught next as they show how organic molecules are distinct from one another. This is related to the naming of organic molecules in that names are based on the functional group of the molecules. So, functional groups need to be taught before naming as naming is a secondary concept that builds on functional groups. The ability to organise a topic according to the most important concepts (Big Ideas in this case) and sequence them logically is an indication of good curricular saliency in the topic.

Curricular saliency is a component of TSPCK that is also related to the quality of CK. As can be seen from the extract for LVM in Figure 6.4 (right), there is awareness that teaching about carbon's unique nature among elements is foundational, since more advanced concepts fit within the context of the uniqueness of carbon. However, it is postulated that LVM had a lack of CK, as the second big idea was naming of compounds followed by functional groups. Naming of compounds is related to

functional groups, in that organic molecules are differentiated from each other according to different functional groups. LVM failed to see this, and this could be because of a lack of CK. She did not realise that the knowledge of functional groups has to precede the naming of compounds, as there are specific rules for naming related to specific functional groups.

Low scoring pre-service teachers generally tried to explain their sequence of Big Ideas, but showed evidence of inadequate CK when they thought a subordinate idea to be a big idea. This shows that CK was essential in order to generate knowledge for teaching related to curricular saliency. It makes sense that pre-service teachers would have difficulty knowing what to teach and when, if they are not sure what their main concepts are. However, even if CK is substantial and coherent, it cannot be assumed that a teacher will also have curricular saliency. The intervention made pre-service teachers aware of knowledge for teaching a particular topic that is different to CK of that topic.

This made these pre-service teachers aware of the “job” that had to be done by them in order to generate TSPCK. It is this awareness that can catalyse pedagogical reasoning about teaching a particular concept effectively. It is possible that a teacher with substantial CK is not aware of the job of pedagogical transformation, and thus will use transmissive teaching styles. It is possible that a teacher with inadequate levels of CK is aware of the job that needs to be done, and tries to avoid traditional styles of teaching, but is limited as Shulman pointed out with his idea of the aspects of pedagogical reasoning (1987). The ideal is teachers with substantial CK that are aware of the TSPCK construct and its usefulness for pedagogical transformation. Therefore, this discussion indicates that, in addition to representations that are specific to the topic, substantial CK of the topic assisted the pre-service teachers to draw conceptually sound insight about the Big Ideas of a topic. This is important as the concept of Big Ideas refers to the understanding of the structure of the topic, a call made by Shulman. He established that teachers need to know CK beyond content but to include structures of the content (Shulman, 1986).

6.4 LOOKING FOR THE MECHANISM FROM INTERVIEWS

I have described the collection of data using oral interviews in Chapter three, but it is important that I highlight a few things relevant to what has been discussed. The interviews with pre-service teachers were conducted only in the topic of transfer, with five of the pre-service teachers chosen on a voluntary basis, depending on availability. The interviews were conducted over a telephone, lasting about thirty minutes with the researcher (myself) taking notes. Audio recording was not possible because of technological limitations in recording a landline conversation, but my notes of the conversation were as detailed as possible.

As this study falls in year 2 of a longitudinal study, the gap between the engagement with the topic of transfer and these interviews was about a year. In order to assist pre-service teachers to recall their reasoning while engaging with TSPCK components, their completed tools were made available to them before the interviews. They were allowed to refer to their responses during the interviews. Therefore, the interviews could be regarded as “recall interviews”. In the analysis, I first reflect broadly on the experience pre-service teachers had when engaging with each of the components of TSPCK in the topic of transfer. According to the response of pre-service teacher KS in the interview (see Appendix E for interview questions), he seemed to rely on CK, and what was learnt at high school in order to generate TSPCK for the topic of transfer. For example, when asked what was considered when formulating an answer to a student with a misconception pertaining to alcohols, KS indicated that he first had to answer for himself the question: “*what is an alcohol?*” Once KS accessed his CK about alcohols, he was then able to pedagogically reason about a suitable way of confronting the misconception of the student. This is evidence pointing towards CK facilitating pedagogical reasoning in the topic of transfer.

When asked about the formulation of Big Ideas, KS indicated that Big Ideas were identified by thinking back to Organic Chemistry concepts taught at school. When asked the reason for sequencing the Big Ideas in a particular order, KS stated that the concepts conceptually build on one another. The interview with KS confirms the process of pedagogical transformation to be a to and fro process between CK and the developing TSPCK, and in the process there is an improved understanding of CK (Mavhunga, 2014b). His interview further confirms the evidence seen in the discussion

above, from the analysis of written responses (extract given in Figure 6.4) of reliance on CK when transforming such CK for teaching purposes in a new topic. What was interesting was that KS seemed to refer back to personal learning of Organic Chemistry at school in order to know what was difficult to teach, and what the Big Ideas were. This indicates that the kind of reflection that facilitates pedagogical transformation might not only be reflection on teaching experience, but on learning experience. This is confirmation of what I speculated in Chapter three (3.4 Intervention), that knowing about the process of learning may inform teaching practice.

6.5 ABOUT THE SEQUENCE OF ENGAGING WITH THE TSPCK COMPONENTS

The order in which KS completed the TSPCK tool for the topic of transfer was consecutive, as presented in the TSPCK tool – starting with learner prior knowledge, curricular saliency, “what is difficult”, representations and conceptual teaching strategies. This sequence is not in accordance with the calculated difficulty order of test items determined through Rasch analysis. In the calculated sequence, the component of representations was easiest. From the quantitative profile for the sample (Table 5.1), one can see that pre-service teacher KS correspondingly found the component of representations the easiest to engage with compared to the other components. During an oral interview, this pre-service teacher pointed out that representations of organic molecules served to concretise abstract concepts, as organic molecules cannot be observed physically. KS mentioned that when a teacher recognises difficult abstract concepts that has to be taught, representations may help to clarify such concepts. His response, however, seems to be generic and lacked an explicit identification of particular aspects that are illustrated through representations. The repetitive use of the representations in the sample even when engaging with other components (see Table 6.3) points to a nonlinear sequence in the mechanism.

When asked whether the intervention for the topic of Electrochemistry assisted to construct TSPCK for the topic of Organic Chemistry, KS indicated that this was not really the case even though he achieved a similar average rubric score of 3 out of 4 for both topics of intervention and transfer. When asked whether knowledge for teaching could be generated in a new topic using the TSPCK framework, KS stated that it is easier to prepare a lesson on a new topic using the TSPCK framework, compared to other strategies that have been attempted.

Another pre-service teacher, SA, was also interviewed telephonically. There were some similarities in answers given compared to KS. For example, relating to the component of learner prior knowledge that deals with learner misconceptions, SA stated that CK was accessed in order to know how to teach the concept of alcohols. The test item required candidates to confront the misconception that all substances with a hydroxyl group are alcohols (see Figure 5.1). Pre-service teacher SA accessed his CK, as with KS, and first provided the standard definition to confront the misconception. SA interestingly referred to curriculum documents in order to determine which concepts were Big Ideas. SA stated that Organic Chemistry subtopics in the aforementioned documents that contained the most information were chosen as Big Ideas.

This indicates an inability to recognise which concept is most important conceptually for the topic of Organic Chemistry. SA achieved an average rubric score of 2 out of 4 for both the topics of intervention and transfer. SA was able to identify which Organic Chemistry concepts were the most difficult by referring back to School science lessons on the same topic. I inquired whether he assumed that concepts that were difficult to learn, would be difficult to teach and SA indicated that this was an assumption he made. Other answers also related to experiences from school days as a learner.

For SA, the sequence in how the TSPCK tool for the topic of transfer was answered was also not according to the rank order established through Rasch analysis. The representation test item was answered last, even though it should have been the easiest to engage with for most pre-service teachers. SA stated, like KS, that representations serves to help students relate to abstract concepts in a way that makes sense to them. SA stated that the TSPCK framework on its own was not sufficient in order to generate TSPCK in a new topic and that teaching experience was the most important factor for teaching practice.

The next pre-service teacher to be telephonically interviewed was JN. As with the case for KS and SA, for the test item related to the TSPCK component of learner prior knowledge, JN referred to CK of alcohols in order to confront the misconception. JN remembered that he had to first know what the standard definition for an alcohol was, before it could be explained. As with KS, JN referred back to the learning of Organic

Chemistry that took place at school in order to identify the Big Ideas. In addition, as with KS, JN argued that the sequence of Big Ideas was logical because certain Big Ideas were prerequisite to others. JN answered the test items of the TSPCK tool for the topic of transfer consecutively according to how they were presented in the tool. When asked about the role of representations in teaching, JN stated that explaining abstract concepts verbally only is not conducive to learning. KS and SA expressed similar views. JN explained that the component of curricular saliency, specifically the question on the concept map, was most difficult to answer. The component of “what is difficult” was for him easiest to engage with. This is contrary to the rank order difficulty of test items established through Rasch analysis. For JN there was no real indication that the intervention that related to Electrochemistry helped to generate TSPCK in a new topic. Despite obtaining a relatively high average rubric score, JN indicated little faith in the TSPCK framework to assist in preparing for a lesson on a new topic without formal teaching experience.

MMJ was the fourth pre-service teacher interviewed. She also referred to CK in order to confront the misconception in the test item related to learner prior knowledge. MMJ referred back to school learning of Organic Chemistry in order to decide what was difficult to teach. I queried MMJ as to why thinking back to what was learnt at school would assist her in knowing what was difficult to teach if the context was learning and not teaching. MMJ replied that she figured that if a topic was difficult to learn, it would be difficult to teach as well. SA had a similar sentiment. For a test item related to the component of representations MMJ chose a representation at sub-micro level and explained that the reason she chose it was because it made the content to be taught clearer. For the test item related to the component of teacher strategies MMJ devised a strategy to compare the molecule in question to another related, but different molecule. In contrasting the two, she hoped that misconceptions would be alleviated.

It was interesting that when asked about the use of representations in teaching, MMJ indicated that visualisation was more effective than only hearing about abstract concepts. JN has a similar sentiment. Most pre-service teachers during the oral interviews seem to have reasoned similarly on the usefulness of representations. MMJ found teacher strategies the most difficult TSPCK component to engage with, and curricular saliency the easiest. This sequence is close to that established by Rasch

analysis. According the rank order of difficulty for test items established by Rasch analysis, teacher strategies was the most difficult component engaged with, and curricular saliency was the second most difficult component engaged with by the sample. MMJ found that the intervention on Electrochemistry helped in that it facilitated engagement with TSPCK components in generating knowledge for teaching a particular topic. MMJ thought that the TSPCK framework would be useful in order to teach a new topic.

ANM was the last pre-service teacher to be interviewed. Despite a high average rubric score for the topic of transfer, she struggled to remember her reasoning processes when completing the Organic Chemistry TSPCK tool. When asked how she was able to identify Big Ideas, she stated simply that it was self-evident when reference is made to CK. Furthermore, in order to sequence the Big Ideas, ANM argued that a measure of logic was involved as some Big Ideas were prerequisite to others, similar to the sentiment of most of the other pre-service teachers interviewed. ANM explained that she made recourse to CK in order to know what is difficult to teach. She was quite frank in stating that she guessed some of the answers, and yet ANM obtained one of the highest rubric scores for the topic of transfer.

From the data of the telephonic interviews one can infer that a number of pre-service teachers in the sample might not be aware of their PCK in the topic of Organic Chemistry. For example ANM and JN both scored 4 out of 4 for the test item related to learner prior knowledge compared to KS and MMJ who scored 2 out of 4, and SA who scored 1 out of 4. Yet, despite the differentiation in their rubric scores, all indicated during the oral interviews to have referred to their CK in order to answer this question. Though CK about alcohols was essential in order to devise knowledge for teaching it, there are other considerations that had to be made. ANM and JN scored full marks for the test items on learner prior knowledge for the topic of transfer, which would not have been possible if they simply provided the standard definition, yet they seem to assume that this is basically all they did. This is proof of the tacit nature of PCK.

The analysis from the completed TSPCK tools and the oral interviews reveals the importance of CK as an important means and resource that is constantly drawn from for successful pedagogical transformation of a topic. It is further noticed how the

interviewed pre-service teachers seem to recognise the importance of the component of representations, which was mostly specifically at sub-microscopic level even when engaging other components of TSPCK. However, they were unaware of how specific to the topic these sub-microscopic representations were and rather resorted to reasons that are generic and related to pedagogical knowledge rather than TSPCK. For example, some of the interviewed pre-service teachers seemed to believe that engaging with the component of representations for the topic of Organic Chemistry was important because representations in general serve to concretise abstract concepts. Nonetheless the interviewed pre-service teachers confirm use of representations as a way of pedagogically transforming the new topic. In the next chapter, detailed discussions of these findings as well as concluding remarks are given.

CHAPTER 7

DISCUSSION OF FINDINGS FROM THIS STUDY

7.1 INTRODUCTION

In Chapters four and five, written responses for both the topic of intervention and topic of transfer were analysed, and it was found that the quality of TSPCK for this cohort of pre-service teachers was of developing quality in both cases. Chapter five concluded by arguing that because of this finding, there is evidence of transfer of learnt reasoning in the topic of transfer. In Chapter six both written responses and oral interviews were investigated in order to determine the mechanism used by pre-service teachers in the transfer of their learnt reasoning to a new topic. A few interesting findings were discussed. In this final chapter I discuss the findings of this study as it relates to the research questions my question of concern. I conclude with implications for teacher education programmes and comment on the observation of ethical considerations in the study, and its limitations.

7.2 SUMMARY OF STUDY

This study is based on the belief that PCK is topic-specific in nature. Shulman (1987), the progenitor of the theoretical construct of PCK, suggested that teachers engage in a pedagogical reasoning process. One aspect of this process is the transformation of “comprehended ideas” (which can be interpreted as CK). According to Shulman, the transformation component is the most important element in the pedagogical reasoning process. Therefore, it is important to identify and possibly develop this skill to transform CK, in particular by pre-service teachers. The reference to skill in this context refers to knowing how to engage with TSPCK components in order to pedagogically transform CK in a topic. The result of the application of this skill is the measured quality of TSPCK present in the cohort of pre-service teachers. It is therefore important to note that the development of TSPCK in the topic of intervention (Electrochemistry) in this study was grounded on learning the skill to transform CK of the topic.

The importance of reasoning through CK for teaching purposes is further demonstrated by Shulman in his statement, “*To reason one’s way through an act of teaching is to think one’s way from the subject matter as understood by the teacher*”

into the minds and motivations of learners" (Shulman, 1987, p. 16). Since CK for different chemistry topics is unique, reasoning through each topic during the process of pedagogical transformation may be unique as well. Perhaps this contributes to knowing why PCK is topic-specific in nature. In this study we were interested in how pre-service teachers were able to think about teaching a new topic in chemistry from the perspective of the TSPCK framework, and consequently transforming the CK in the new topic for the purposes of teaching. Because of the tacit nature of PCK, measuring the quality of TSPCK for pre-service teachers was best achieved using a Mixed Methods approach. I started by looking at the qualitative written responses which were converted to quantitative data, i.e. scores generated from the TSPCK rubric. This was done with the written responses for both topics, i.e. topics of intervention and transfer using a TSPCK rubric. Rasch statistical analysis was used to enable the calculation of reliability of both test items and persons, and also check the validity of the TSPCK tools used in the study. Probably the most significant benefit of working with quantitative data was being able to establish a rank order of difficulty of test items, and therefore TSPCK components, for both topics of intervention and transfer.

Knowing which test item was experienced as easiest provided insight into the mechanism used for the pedagogical transformation of CK. A further clue into the mechanism related to the comparison of the sequence in which pre-service teachers engaged with the components during completion of the TSPCK tools, vs. a sequence or pattern emerging on how they used the components to transform their CK as seen from the data. I had both the written responses and the oral interviews that could help me elucidate sequence of engagement with TSPCK components. The research questions in Chapter one served as a guide to know what had to be done at a particular time during my study. A discussion of the findings of this study with respect to these research questions follows.

7.3 RESEARCH QUESTIONS REVISITED

7.3.1 Research questions 1 and 2

The first research question was: To what extent is TSPCK developed in the topic of intervention and that of transfer? This question partially subsumes the next research question: To what extent has transfer of learnt reasoning happened in a new chemistry

topic? My response combines answers to both research questions 1 and 2. The quality of TSPCK developed in Electrochemistry through an intervention was improved to an extent of a developing level according to the TSPCK rubric used in the study. Similarly, the quality of TSPCK developed in a new topic (Organic Chemistry) by transfer of the learnt reasoning was also developed to an extent of a developing level of quality. This means the quality of TSPCK in the new topic (the topic of transfer) was developed to the same extent as that in the topic of intervention. The TSPCK rubric used had categories related to the five components of the TSPCK construct, where the criteria related to a specific level of quality (i.e. Basic to Exemplary) that progressively increased in terms of depth of knowledge how to use the component to transform CK for teaching purposes. It must be noted that the developing level of TSPCK quality according to the TSPCK rubric used in the study is one level away from the exemplary level of quality that would be displayed by expert teachers.

This finding, in a new topic, is therefore encouraging given that these are pre-service teachers. The finding is similar to that determined by Mavhunga (2014b), where a similar level of development of TSPCK in a new topic (Chemical Equilibrium) by transfer was observed. Therefore this study provides significant insight into the mechanism that enables such a successful transfer of the learnt pedagogical transformation skill. In Chapter six it was shown that the pre-service teachers based their pedagogical reasoning on understanding of CK, a process that required engagement with content. The two extracts in Figure 6.4 were discussed and used to demonstrate success and failure in using CK to justify sequencing of Big Ideas.

This observation indicates that the process of pedagogical transformation in a new topic demands interrogation of CK in the topic. Therefore, having knowledge of the TSPCK construct and its five components is not sufficient to perform pedagogical transformation of CK in a new chemistry topic. TSPCK can only transform CK in a chemistry topic, if there is engagement with the relevant CK. This confirms the topic-specific nature of TSPCK, and the transfer of learnt reasoning or “know how” that enables pedagogical transformation of CK. This learnt reasoning refers to a skill that is present when TSPCK allows pedagogical transformation of CK in a topic. In summary of the findings related to the first two research questions, the pedagogical transformation skill could be used as a vehicle to both develop TSPCK for a chemistry topic in an intervention, and once understood could be re-applied to transform CK of

a new chemistry topic. In the aforementioned process it was found that the development of TSPCK in the topic of transfer was to the same quality as in the topic of intervention. While I cannot generalise these findings, it is true for the topics in this study, and those initially investigated by Mavhunga (2014b).

7.3.2 Research question 3

Research question three was the main focus of my study: What mechanism do pre-service teachers use to engage in pedagogical transformation of a new topic in Chemistry? The findings point to three aspects that could be identified as contributing to the mechanism in which pre-service teachers applied the learnt reasoning that enables pedagogical transformation in a new topic.

7.3.2.1 The importance of content knowledge

In order to understand such a mechanism, one can generally ask “what” is being used, and in “which sequence”. If one thinks of biological systems that involves clear mechanisms, one can follow a particular sequence with clear understanding of what organ parts are used. For example, in order to understand the mechanism of photosynthesis one has to know what substances and plant organs are involved, and then also in which sequence processes occur. In the discussion below, I start with what knowledge is being used in attempting transformation of CK in a new topic.

From the findings of this study, the “what” was found to be the understanding of CK in the topic. It could be said that it is self-evident that transforming CK requires substantial CK which can be transformed for teaching purposes. It was evident from both the written responses and oral interviews that pre-service teachers relied on their CK when identifying Big Ideas and sequencing them for teaching as they engaged with the component of curricular saliency in the topic of transfer. Once again I quote Shulman in one of his seminal papers: *“To reason one’s way through an act of teaching is to think one’s way from the subject matter as understood by the teacher into the minds and motivations of learners”* (Shulman, 1987, p. 16). In a way it is impressive that these pre-service teachers with little teaching experience were aware that they have to engage with their CK when reasoning about teaching a specific topic. Loughran, Mulhall, and Berry (2004) found a way to identify Big Ideas for a topic, but generally

the process requires input from a panel of teachers, with at least some teaching experience, involved in intense discussion. These novice pre-service teachers had to identify Big Ideas by themselves. Therefore, it is quite surprising that only one pre-service teacher made reference to policy documents, a weak reference, in order to identify Big Ideas and sequence them for teaching.

Pre-service teacher SA stated that he made reference to curriculum documents in order to know what the Big Ideas were for the topic of transfer (Organic Chemistry), and how to sequence them for teaching. I mention here that SA achieved one of the three lowest rubric scores for both topics of intervention and transfer if the average rubric scores are not rounded off. This phenomenon aligns with the validity of the TSPCK tools as it can be expected that SA had low quality TSPCK based on how he identified Big Ideas and how he sequenced them for teaching.

7.3.2.2 Representations as a “way in”

It was also observed that when pre-service teachers engaged with their CK for pedagogical transformation, they made recourse to the TSPCK component of representations. This was observed from the written responses for the topic of transfer. Through Rasch analysis it was established that representations was the easiest of the TSPCK components to engage with for the cohort of pre-service teachers. This was unique to the topic of transfer, confirming once again that TSPCK and the process of pedagogical transformation of CK is unique to a topic. From analysis of the written responses for the topic of transfer, I speculated that pre-service teachers used the easiest component of TSPCK to engage with more difficult components. Evidence of this interactive process was observed in the written responses where pre-service teachers made recourse to TSPCK components other than representations, in answering test items related to the component of representations.

7.3.2.3 A cyclic interactive process

The sequence of engagement with the five components of TSPCK was presented to pre-service teachers in a linear fashion in the intervention, one component after another. The same sequence was used to present engagement in the TSPCK tools for both topics. Looking at the presented sequence it is first the component of learner

prior knowledge, then curricular saliency, “what is difficult”, only then representations and lastly conceptual teaching strategies. However it was noted that while engaging with learner prior knowledge and conceptual teaching strategies, pre-service teachers used representations consciously or automatically (confirmed in oral interviews). Therefore, the interactive use of representations with other components of TSPCK points to a mechanism that is not linear but a series of small cyclic interactions between the component of representation and others. This mechanism may be unique to the discipline of Chemistry because of the abstract nature of Chemistry topics. Therefore, it may be inherent that Chemistry is more visual in nature as representations facilitate understanding of abstract Chemistry topics.

For the first component of learner prior knowledge found in the Organic Chemistry TSPCK tool, seven out of the sixteen pre-service teachers made reference to a representation when confronting a misconception. Learner prior knowledge was the second most difficult TSPCK component engaged with according to Rasch analysis from the written responses of the topic of transfer. Since representations was the easiest component engaged with, perhaps pre-service teachers first engaged with representations in order to subsequently engage with learner prior knowledge.

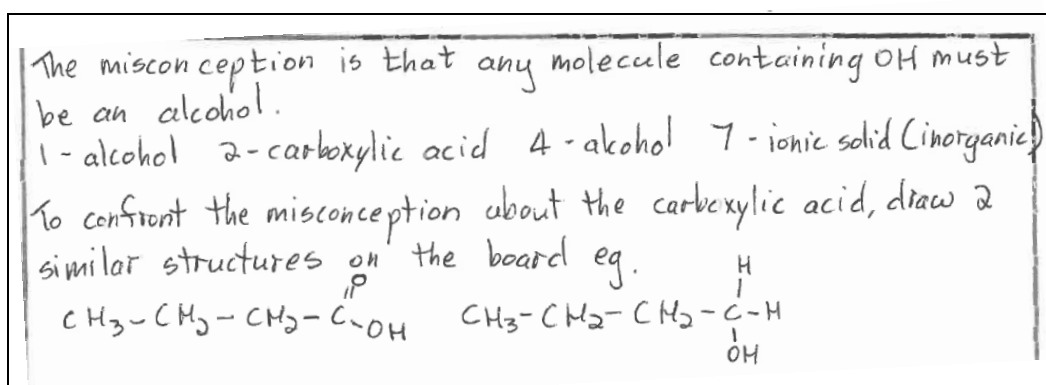


Figure 7.1: Extract from learner prior knowledge test item for topic of transfer

In the extract from Figure 7.1 it is possible to see how pre-service teacher ANM engaged with representations first in order to confront a learner misconception. In addition nine out of sixteen pre-service teachers also used representations in order to engage with the TSPCK component they found most difficult, namely teacher strategies. It seems that the sequence of engagement with the five components of TSPCK for the topic of transfer was not linear.

Below in Figure 7.2 an illustration of the observed sequence of engagement from written responses is given.

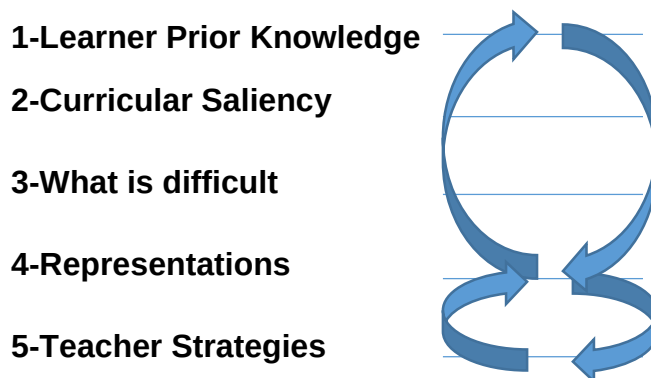


Figure 7.2: An illustration of the sequence of engagement for topic of transfer

Figure 7.2 shows how the sequence of engagement had more of a cyclical nature, than a linear one. After seeing this cyclic nature, where the component found easiest is used to engage other more difficult components in a topic, I became interested to see whether similar patterns emerged in the topic of intervention (Electrochemistry).

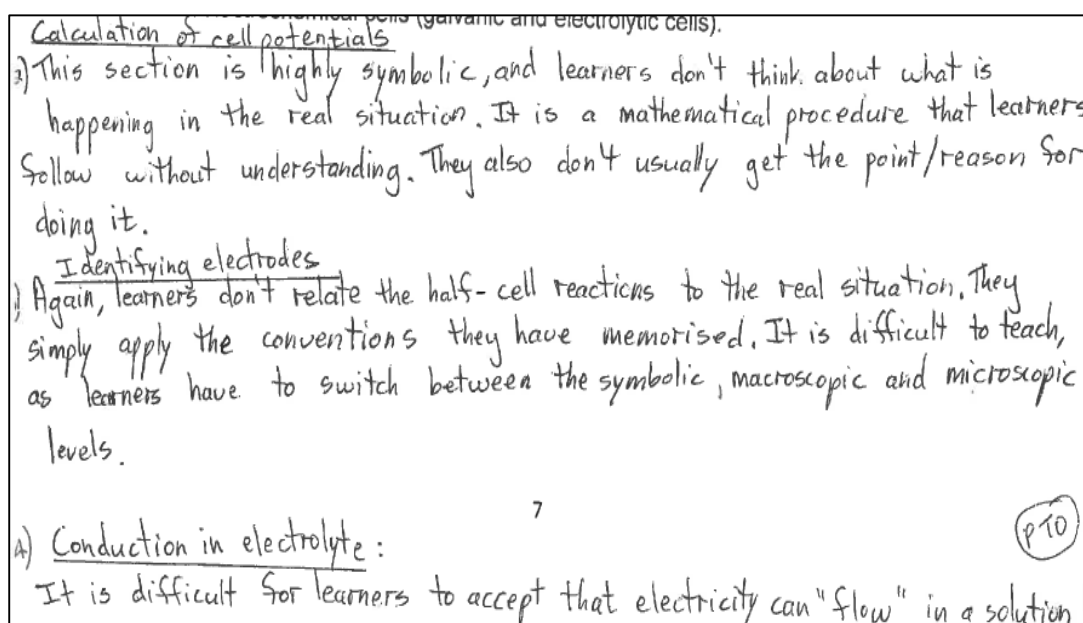


Figure 7.3: Extract from "what is difficult" component for topic of intervention for ANM

In Figure 7.3, one can see how pre-service teacher ANM made recourse to learner prior knowledge in order to engage with the "what is difficult" component of TSPCK.

For example, she indicates that conduction in an electrolyte is difficult to teach because it is difficult for students to accept that electricity can “*flow in a solution*”. What was of interest is that for the topic of intervention, learner prior knowledge was the easiest component of TSPCK to engage with for the sample according to Rasch analysis. I wanted to know whether this was an isolated case, so I looked at all the completed questionnaires for the topic of intervention again.

Concept	✓	Why is it difficult to teach?
Cell construction Galvanic vs. electrolytic cells	✓	Learners tend to put Anode to be positive in both, learners assume that anode is positive.
The calculation of cell potentials	✓	• Learners tend to use the wrong equations e.g. $E^{\circ}_{\text{cell}} = E^{\circ}_{\text{anode}} - E^{\circ}_{\text{cathode}}$.
Identification of anode and cathode using E° values/ Using half- cell reactions to identify the electrodes	✓	• Learners confuse the signs, they put positive, where it's supposed to be negative.
Conduction in the electrolyte		
Electrical neutrality	✓	• Because learners don't grasp the function of the salt bridge
Working with the electrode potential values		
Deciding positive and negative electrodes in galvanic and electrolytic cells	✓	Learners always think that electrons move from positive to negative electrode always, so they then put anode to be positive in both the electrode cells.

Figure 7.4: Extract from “what is difficult” component for topic of intervention for KS

For pre-service teacher KS, the above extract in Figure 7.4 shows that learner prior knowledge assisted engagement with the “what is difficult” component of TSPCK as is the case with ANM. For example, KS indicated that cell construction was difficult to teach, because “*learners tend to put Anode to be positive in both, learners assume that anode is positive*”. Here KS shows the contrast between the anode of an electrolytic and galvanic cell, i.e. that in the former the anode is positively charged but in the latter it is negatively charged. KS seem to be aware that students might assume that the anode is either always positive or negative, making this difficult to teach. I wondered if pre-service teachers used the easiest component of learner prior knowledge for the topic of intervention to engage with yet another TSPCK component, besides “what is difficult”. This question arose because in the topic of transfer pre-service teachers used the easiest component of representations to engage with two

other TSPCK components. A diagram is given below in Figure 7.5 to show the sequence of engagement for the topic of intervention.

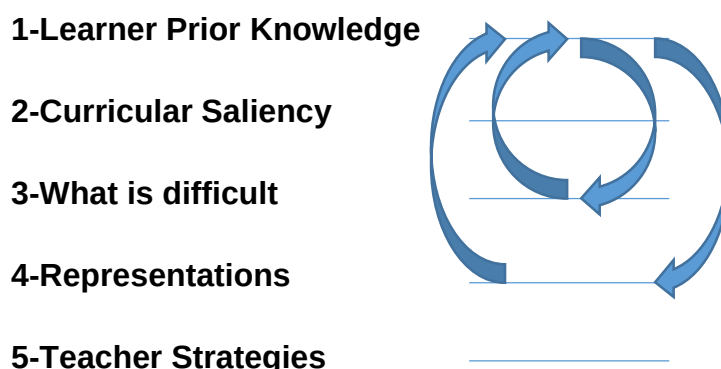


Figure 7.5: An illustration of the sequence of engagement for the topic of intervention

This finding again emphasises that the process of pedagogically transforming CK is unique to each topic. Again a cyclical nature of engagement is shown, as with the topic of transfer. In addition, as with the topic of transfer, it was the easiest component of TSPCK that was used in the topic of intervention in order to engage with more difficult components.

7.4 CONCLUSION ON MECHANISM FOR TRANSFER OF LEARNT REASONING

Pre-service teachers obtained a skill during the six week intervention during which they engaged with their CK in order to transform it for teaching purposes using the TSPCK framework. Transfer of learnt reasoning that occurred for most of the pre-service teachers from the topic of intervention to the topic of transfer involved awareness that CK had to be transformed using the TSPCK framework for a specific topic. This awareness and the skill to apply the five components of TSPCK when pedagogically transforming CK is what was transferred, and as most of the pre-service teachers indicated during oral interviews, they had the confidence to prepare to teach a new topic using the TSPCK framework. I postulate that this confidence stems from the inherent awareness of what they need to do when it comes to preparing to teach a new topic. The sequence of engagement with components of TSPCK reveals a cyclical nature, rather than a linear nature. Pre-service teachers seemed to have made recourse to easier components of TSPCK in order to engage with more difficult components.

Many of the components of TSPCK seem to be interrelated as seen from both topics. For example, in order to confront a misconception (related to the TSPCK component learner prior knowledge), a pre-service teacher might utilise a representation (as was observed in the topic of transfer), or refer to knowledge of the curriculum in order to know what to emphasise. In addition, in order to confront the misconception, a comprehensive teacher strategy might be constructed. The same could be said for other components.

For example, with regards to the TSPCK component “what is difficult”, in order to know what is difficult to teach for a particular topic a teacher might first refer to common learner misconceptions (as with the topic of intervention), and then refer to specialised teaching strategies that will confront such misconceptions before it is decided that a particular concept of a topic is difficult to teach. Also, when selecting a representation for teaching a particular topic, a teacher might first think about common misconceptions related to the concept. One representation might address the misconception more adequately than another. Lastly, for a teacher to construct a teaching strategy to confront a learner misconception, the components of curricular saliency, “what is difficult”, and representations may be engaged with as well. There seems to be an interrelatedness between the components when a teacher engages with one particular component in order to pedagogically transform CK for teaching purposes.

The above comments are not merely conjectural, but are corroborated by data from both written responses and oral interviews in this study. Findings from this study aligns with those of Park and Chen who found that:

Overall, the findings of this study converge on the point that the synthesis of the components into PCK is not a straightforward process related primarily to simple possession of those components. Rather, the constructions of PCK are largely influenced by the interaction of different components. (Park and Chen, 2012, p. 939)

Chen and Park (2012, p. 939) continues as follows: *“Lack of coherence among the components can be problematic in developing PCK”*. I therefore include in the postulated mechanism for transfer of learnt reasoning this ability inferred by Chen and Park, namely that the interrelatedness of components of TSPCK must be perceived by the teacher. In this study for both topics of intervention and transfer it was observed that recourse was made to the easiest TSPCK component when engaging with more difficult TSPCK components. It could be inferred that possibly some of the pre-service teachers who showed this skill were aware of the interrelatedness of TSPCK components when transforming CK for the purpose of teaching. Finally the role of CK could not be underplayed. My question of concern for this study is again:

How can the benefits of a rigorous and in-depth programme targeting development of PCK in a specific chemistry topic, through explicit discussion of the pedagogical transformation skill, be maximised for continuous transfer across other chemistry topics?

Therefore, in order to successfully transform CK in a new topic for the purposes of teaching, a teacher needs substantial coherent CK and an awareness that such knowledge needs to be engaged with for pedagogical transformation using the TSPCK framework, and an awareness of the interrelatedness of the TSPCK components. Such “benefits” were gained by the sample of pre-service teachers through a six week intervention which facilitated pedagogical reasoning in an explicit manner, using the five TSPCK components, in order to transform CK for the topic of Electrochemistry for teaching purposes.

7.5 THE OBSCURE NATURE OF TSPCK

One observation from the oral interviews relates to the tacit nature of TSPCK. Pre-service teachers during their fourth year of BEd studies were explicitly taught about the TSPCK theoretical construct, and its five components in a six week intervention, and completed the TSPCK tools for both topics of intervention and transfer shortly afterwards. Two of the pre-service teachers who were telephonically interviewed, namely JN and ANM, are currently active first year teachers. When ANM was asked

during the oral interview “*Do you think you could use the TSPCK framework each time you plan to teach a new topic?*” ANM answered that she could not do so consciously. This was an interesting answer. ANM seemed to indicate that there is superficial knowledge about the TSPCK framework, but when she prepares for lessons the TSPCK components are not engaged with explicitly. JN, the other practising novice teacher, indicated that using the TSPCK framework was “tedious” and that teaching experience contributed more towards effective teaching. This is ironic, as both JN and ANM obtained high average rubric scores for both topics of intervention and transfer.

It is possible that such teachers are not aware of their TSPCK, and might assume their main knowledge base for teaching to be CK per se, instead of realising that they are transforming their CK for teaching purposes in the process. If a teacher claims to know how to teach a particular topic in science, such a teacher might not be aware of the transformation process that occurred, and therefore the knowledge base of PCK within a topic is not recognised explicitly. TSPCK is tacit because I believe it is essentially meta-knowledge that can generally be defined as “*a person's awareness/knowledge about his/her own knowledge*” (<http://www.collinsdictionary.com>). Knowledge about how to pedagogically transform CK for teaching purposes could be said to be knowledge about a form of knowledge (CK) as it relates to teaching. If TSPCK is meta-knowledge, it may relate to the field of epistemology in philosophy. I believe this can add to knowledge of the tacit nature of TSPCK and PCK in general. This may partially explain why PCK is a tacit construct of which teachers in general are not explicitly aware.

7.6 REFLECTIONS ON MY EXPERIENCE

Over the past two years, I have struggled quite often to comprehend the knowledge based for teaching that is TSPCK. I have been tempted myself to agree with the statements of some of the pre-service teachers during oral interviews; that once CK is present, knowledge of how to teach it follows logically. More than once my supervisor had to direct my thinking in order to realise that transformation of CK was a process that occurred as knowledge for teaching a particular topic was developed. The TSPCK framework can justify why knowledge for teaching a specific science topic is valid. If a teacher knows that knowledge for teaching a specific science topic is valid because it was formed through pedagogical transformation of CK for that topic, using the TSPCK

framework, then less trial and error may be experienced by novice teachers. Therefore, there may be a way to accelerate the development of TSPCK in novice teachers, and this relates to the future of teacher education programmes.

7.7 IMPLICATIONS FROM THIS STUDY FOR TEACHER EDUCATION PROGRAMMES

In a South African context, improving teacher education programmes is essential, as it is perceived that the expertise of most South African teachers leave a lot to be desired (Rollnick et al., 2008). In order for teacher education programmes to facilitate pre-service teachers to transfer learnt reasoning to new chemistry topics, I refer to the findings of this study. Based on the findings of this study, pre-service teachers need to be aware of the need for pedagogical transformation of CK for teaching purposes, and that the TSPCK framework has been shown useful for this purpose. Pre-service teachers need to be explicitly aware that their quality of their CK will affect their ability to pedagogically transform such CK directly. Moreover, explicit knowledge of interrelatedness of the five TSPCK components when transforming CK might assist pre-service teachers in the process of pedagogical transformation of CK, as recourse could be made to easier components of TSPCK in order to engage with more difficult components.

Interventions similar to the six week intervention which the cohort of pre-service teachers experienced for the topic of Electrochemistry in 2013 could be performed for undergraduate pre-service teachers who are part of teacher education programmes. Following on such an intervention, pre-service teachers could complete specifically designed TSPCK tools for the topic of intervention which could be scored using a TSPCK rubric. Thereafter, pre-service teachers could continue by completing more TSPCK tools for other science topics without any further assistance while progress is monitored through the scoring of such TSPCK tools.

Another recommendation is that some methodology classes be merged with content classes, in which students could learn about scientific knowledge and, at the same time, how to teach it effectively. Pre-service teachers should be assisted to be more aware of mental processes involved in their learning of difficult science topics, and

make an explicit link with the knowledge for teaching such topics. Students should be assisted to pedagogically transform CK as it is learnt using the TSPCK framework. Perhaps this can clarify the nature of TSPCK for novice teachers that are part of a teacher education programme.

7.8 LIMITATIONS OF THIS STUDY

With regard to the oral interviews, one limitation was that the interviewees had completed the TSPCK tools for the topic of intervention and transfer approximately eighteen months earlier. This showed in the oral interview with ANM, as she could not recollect what her reasoning was at the time, even though she had an electronic copy of the completed TSPCK tool during the interview for reference purposes. Another limitation of this study is that of a small sample. The cohort consisted of only sixteen pre-service teachers, which limits any deductions made, even though acceptable reliability and validity were determined through Rasch analysis. All findings of this study are also limited to topics of Chemistry.

7.9 ETHICAL CONSIDERATIONS

I have coded the names of the pre-service teachers in this study. Hard copies of completed questionnaires will be locked away in my supervisor's office. All electronic copies of the documents will be password protected.

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APPENDICES

Appendix A: TSPCK tool for the topic of intervention (Electrochemistry)



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ELECTROCHEMISTRY TSPCK TOOL

PCK Research group

Contact Person: Prof. Marissa Rollnick

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

Code:

Demographic information

Name		
Gender	Female ☐	Male ☐
Current subject (s) taught:		
Number of years of teaching science		
Other subjects taught	Grade	Number of years teaching the grade:
Qualifications:	Institution where obtained	Year

Please fill in details about all your post school qualifications.

Qualification and length of course (e.g. STD - 3yrs)	From (year)	To (year)	Main Subjects

Have you taught electrochemistry? Yes ☐ NO ☐

If yes, indicate the grade and the number of years for each grade:

Grade(s)	Number of Years	Years Taught, e.g. 2007, 2008

Please answer all questions.

CATEGORY A: LEARNERS' PRIOR KNOWLEDGE

1. How do you respond verbally to a learner who writes on a script:

"The electrons flow through the salt bridge to keep the galvanic cell neutral"

Response A: No, this is not the case; the electrons do not flow through the salt bridge to keep the galvanic cell neutral but through the external circuit. Only ions flow through the salt bridge.

Response B: No, this is not the case; electrons need a medium like a wire (solid) which is a good conductor for them to flow. The salt bridge contains a solution and only ions can flow within the salt bridge.

Response C: No, this is not the case; electrons flow through the external wire whereas the ions flow through the salt bridge. The flow of the ions through the salt bridge will maintain the galvanic cell electrically neutral.

Response D: None of the above. I have another response, which is...

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

My choice is Response _____.

2. What will your answer be to a learner who asks:

"Is it true that in both electrolytic and galvanic cells, oxidation always occurs at the anode and reduction always occurs at the cathode?"

Response A: Yes, it is true that in both electrolytic and galvanic cells, oxidation always occurs at the anode and reduction always occurs at the cathode. The electrons may be lost by the anode material or by the ions near the anode and gained by ions near the cathode.

Response B: Yes, it is true that in both electrolytic and galvanic cells, oxidation always occurs at the anode and reduction at the cathode. The difference is that, in the electrolytic cell the anode is positive while the cathode is negative and vice versa for the galvanic cell. Note that electrons flow from the anode to the cathode.

Response C: Yes, it is true, in both electrolytic and galvanic cells, oxidation always occurs at the anode and reduction at the cathode. However, in the electrolytic cell the cathode has a negative charge and the anode has a positive by virtue of being connected to the positive terminal of the cell.

Response D: None of the above. I have another response, which is...

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

My choice is Response ____.

3. Reflecting on your experience of teaching electrochemistry, what misconceptions have you observed common in this topic?

Write your answers in the spaces given below:

--

CATEGORY B: CURRICULAR SALIENCY

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

- 4.1 What concepts in electrochemistry at Grade 12 do you believe are the main ideas¹ for understanding by students at the end of the instruction of this topic?

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

Oxidation and reduction occur simultaneously.	Equations must be balanced
Energy from chemical reactions can produce electricity	Electrochemistry has important applications in everyday life
Electrical neutrality is preserved in a cell	Electroplating processes use redox reactions
Electrode potentials are linked to the energy of the half reaction	Calculation of cell potentials
Half- cell reactions are linked to electrode potential	Galvanic cells produce electricity
Ions carry charge in solution	Other
Electricity can be used to produce a chemical reaction.	

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

Suggested concepts and sequence	Reasons
1.	
2.	
3.	

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

List of Topics to be taught before electrochemistry



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

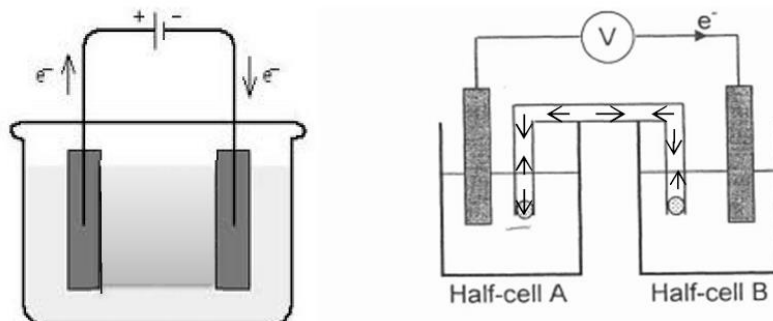
5. What concepts do you find difficult to teach in electrochemistry? Select your choice and provide reason(s) in the table below.

Concept	✓	Why is it difficult to teach?
Cell construction		
Galvanic vs. electrolytic cells		
The calculation of cell potentials		
Identification of anode and cathode using $E^\ominus$ values/ Using half- cell reactions to identify the electrodes		
Conduction in the electrolyte		
Electrical neutrality		
Working with the electrode potential values		
Deciding positive and negative electrodes in galvanic and electrolytic cells		

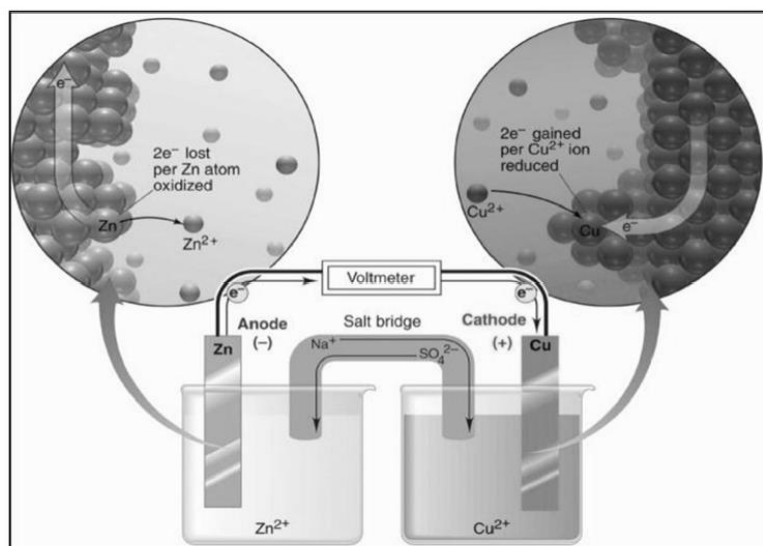
CATEGORY D: REPRESENTATIONS/ANALOGIES/MODELS

6. Below are possible representations for teaching the concept of electrochemical cells (galvanic and electrolytic cells).

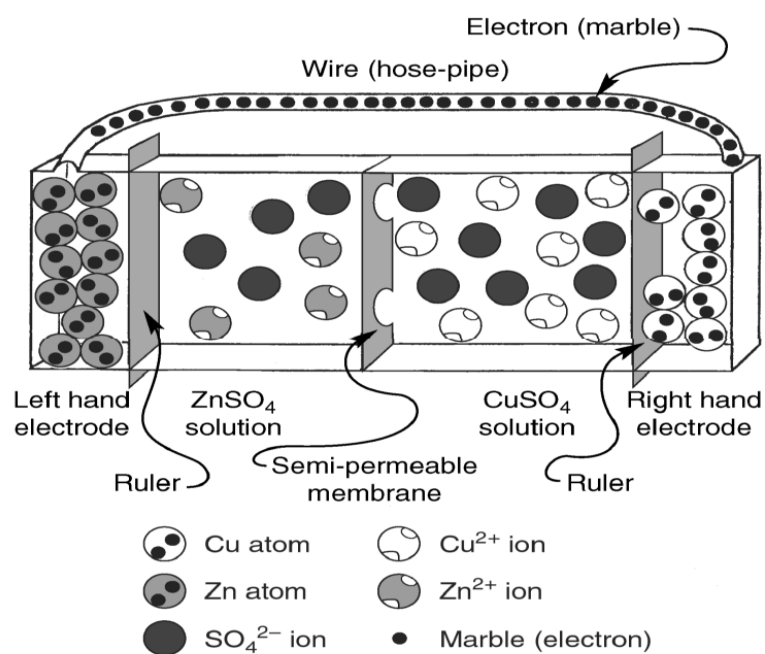
Representation 1



Representation 2



Representation 3



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

Representation No.	What I like	What I do not like
1		
2		
3		

6.2 Which representation do you like most?

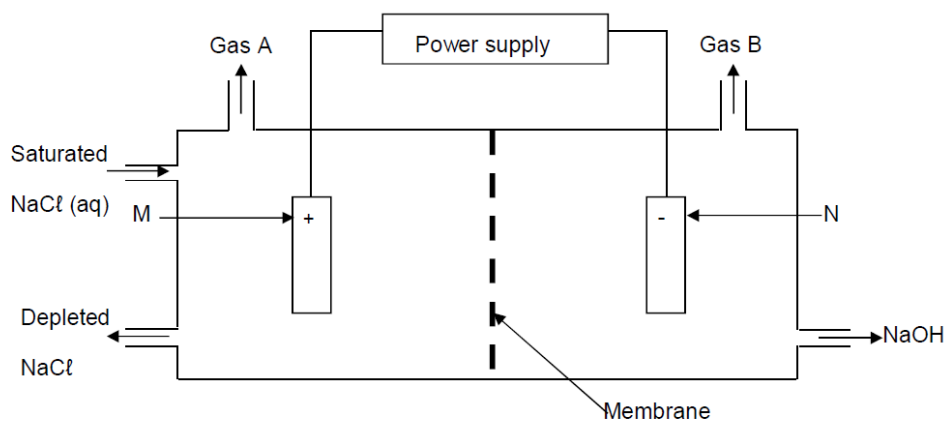
6.3 How would you use the representation that you like most in a lesson?

CATEGORY E: CONCEPTUAL TEACHING STRATEGIES

7. Learners are given the following task:

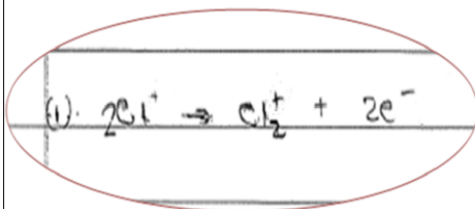
You ask learners to study the membrane cell shown in the diagram below and determine which products will form during the electrolysis of a saturated salt solution.

Let's assume you ask the learners to write down the equation for the half-reaction taking place at the electrode M.

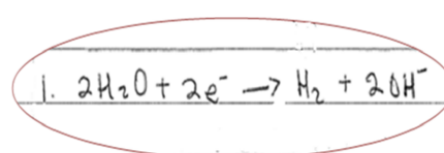


The learners provided the answers below:

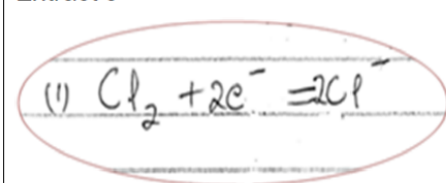
Extract 1



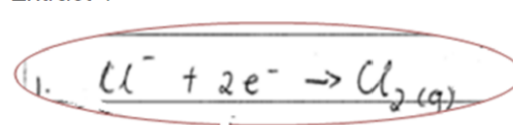
Extract 2



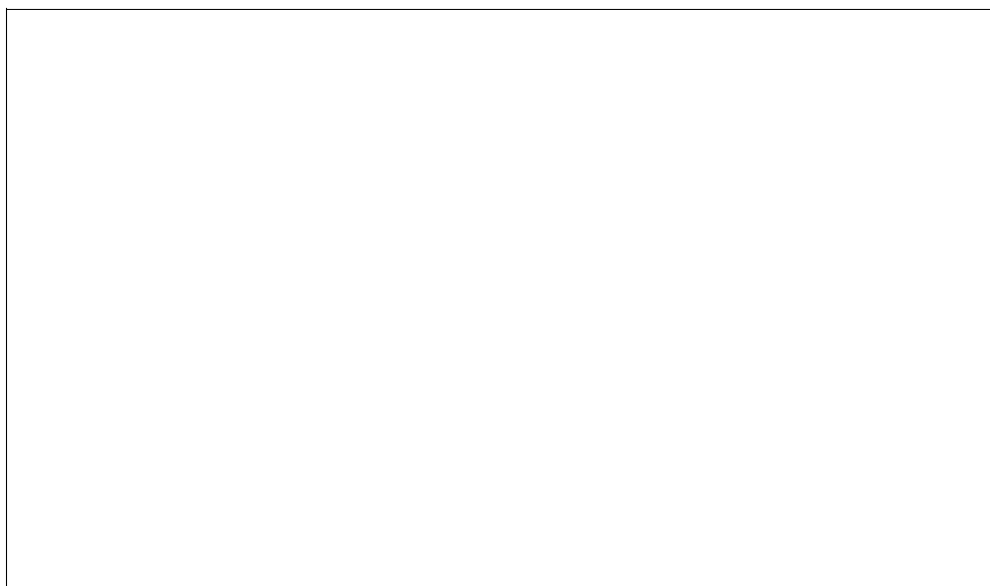
Extract 3

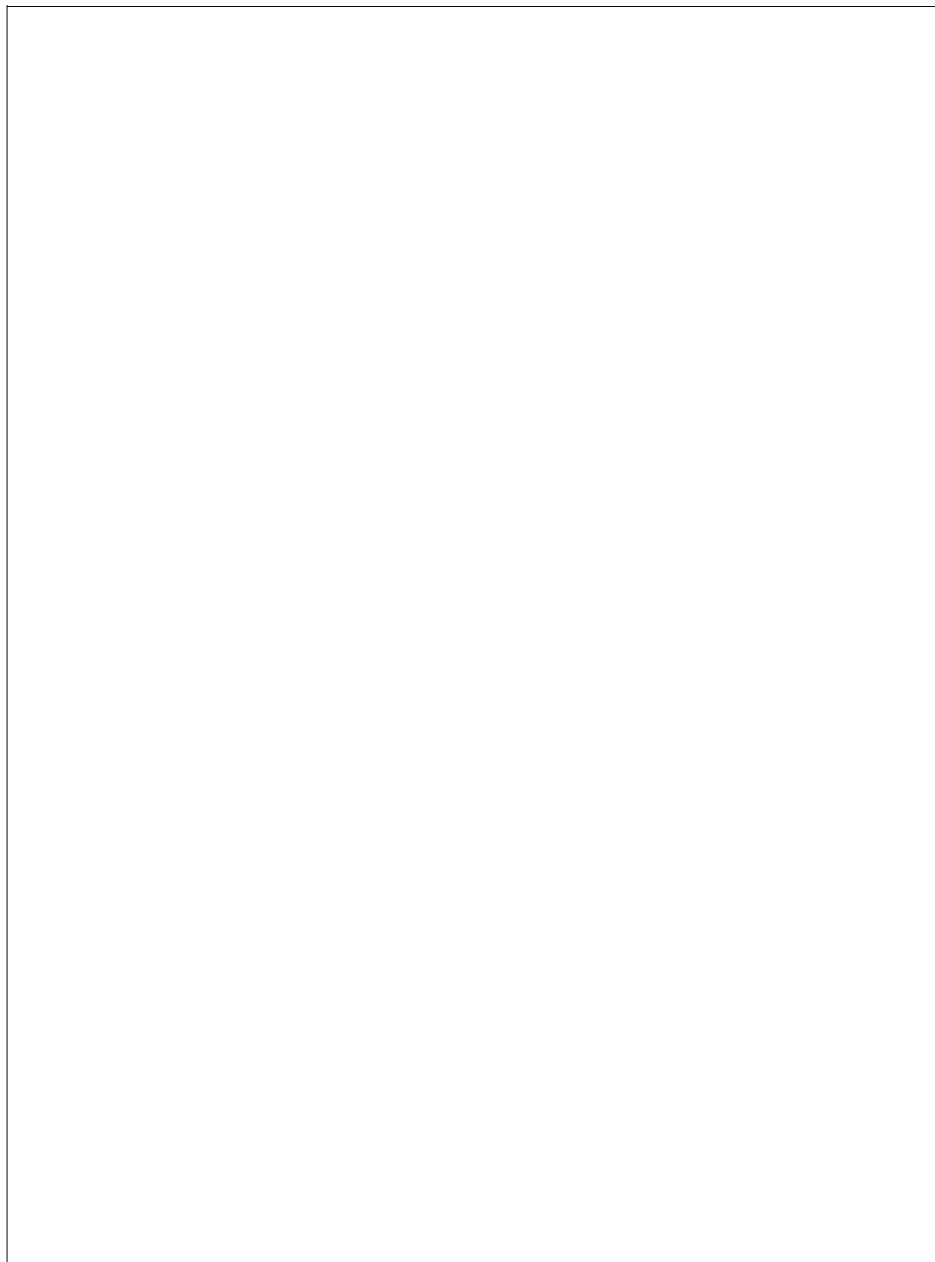


Extract 4



Explain how you would assist these learners to move towards the correct answer explaining what their errors are.





Thank you!

Appendix B: TSPCK tool for topic of transfer (Organic Chemistry)**ORGANIC CHEMISTRY RESEARCH PROJECT – QUESTIONNAIRE 2**

This information is for research purposes only: your responses will be treated confidentially. Pseudonyms will be used if a need to refer arises. This page will be detached and stored separately.

BACKGROUND INFORMATION

SURNAME: _____

NAME _____

Gender (tick✓):

Female	Male
--------	------

HOME province and town: _____

Personal Code:

Personal code:

Section A: STUDENT'S PRIOR KNOWLEDGE

1. You hand out a worksheet to be used in a classroom activity and ask students to select compounds that are alcohols from the table below:

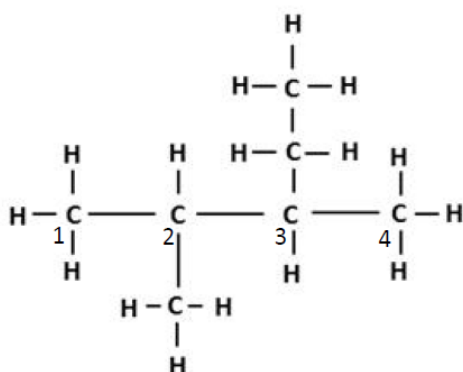
1 $\text{CH}_3\text{-OH}$	2 $\text{CH}_3\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-OH}$	3 $\text{CH}_3\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-H}$	4 $\text{CH}_3\text{-CH}_2\text{-OH}$
5 $\text{CH}_3\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-CH}_3$	6 $\text{H}\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-O-CH}_3$	7 NaOH	8 $\text{CH}_3\text{-}\overset{\text{O}}{\parallel}\text{C}\text{-O-CH}_3$

Sipho selects compounds 1, 2, 4 and 7. You then realize that other students in the class have given the same response. How would you explain to the students in the class how to distinguish alcohols from other compounds?

Personal code:

2. You have asked the students in your class to name the compound below according to the IUPAC rules. You encourage students to work in pairs to complete this task.

Mary is confused about naming the compound and asks Charlie for help. Charlie starts by identifying the longest chain from left to right and ends up with four carbon atoms numbered as shown on the diagram below. He names this compound butane, he then states that there is a methyl group at C2 and an ethyl group at C3.



Both Mary and Charlie agree that this compound is 2-methyl-3-ethyl-butane. How would respond to these two students?

Personal code:

Section B: CURRICULUM AWARENESS

1. Which of the following would you consider the **four** most important chemical concepts that must have been covered in chemistry before you can teach organic chemistry? Indicate your choice with a tick [✓] next to each concept that you choose, and give a reason for your choice. You can also add any other concepts.

Concepts	✓	Reason
The atom		
Periodic Table		
Chemical bonding		
Mole and stoichiometry		
Electronegativity		
Intermolecular forces		
Gas laws		
Acids and bases		
Electrochemistry		
Chemical equilibrium		

Personal code:

2. Which of the following would you consider to be the **three main concepts (big ideas)** to be taught in organic chemistry at Grade 12? Indicate your choice with a tick [✓] next to each concept that you choose.

Concept	
Carbon has a unique nature	
Organic compounds are named according to the IUPAC system.	
Alkanes have unique properties.	
There is a relationship between physical and chemical properties	
Some acids belong to the homologous series known as carboxylic acids.	
There are different ways of representing organic substances.	
There are several major types of reactions for organic materials.	
Structural isomers have the same molecular formulae.	
Alkenes undergo combustion.	
Functional groups in organic chemistry tell us about the different types of compounds.	
Empirical formulae tell us how many atoms of each kind are present in compounds.	

3. In the table below list these main concepts you have chosen in the order in which they should be taught.

Personal code:

4. Explain briefly your reasons for the order you chose.

5. Make a map or a diagram of the three concepts which you chose in 2 above showing how they link to subordinate concepts.

Personal code:

Section C: WHAT MAKES THE TOPIC DIFFICULT TO TEACH?

Which of the following organic chemistry sections (topics) do you consider difficult to teach? Explain why these topics are difficult to teach.

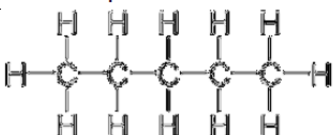
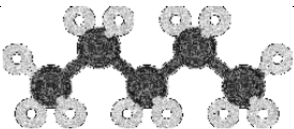
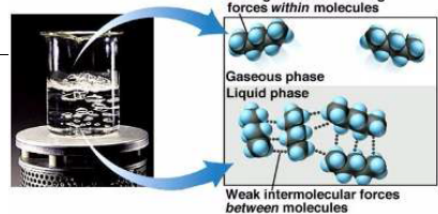
Concept	Why is it difficult to teach the concept?
Molecular formulae	
Structural formulae	
Functional groups	
IUPAC names	
Isomers	
Homologous series	
Types of organic reactions e.g. substitution, addition and elimination	
Combustion	
Esterification	

Personal code:

Section D: REPRESENTATIONS/ANALOGIES/MODELS

1. There are many ways of representing a molecule with molecular formulae C_5H_{12} , (pentane). Representations for C_5H_{12} are shown below.

- a) Which representations do you find the most useful?
- b) Complete the table and describe when you would use each of these representations in your teaching.

	Representation	Use in teaching
1		
2		
3	$CH_3-CH_2-CH_2-CH_2-CH_3$	
4		
5		

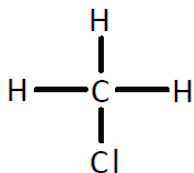
Section 5 continued

- c) How would you use the representation(s) that you chose in (a) on the previous page to explain the differences in the boiling points of butane ($-0.5^\circ C$) and pentane ($36^\circ C$)?

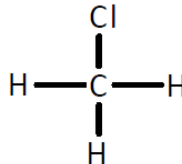
Personal code:

Section E: TEACHING STRATEGIES

1. You draw the structure of chloromethane as shown below on the chalk board.



Teacher's Drawing

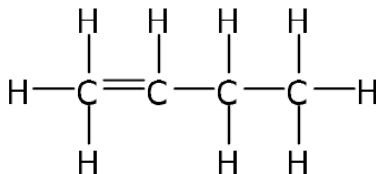


Student's Drawing

A student asks: "Is it okay if you swap around the chlorine and a hydrogen atom like this (the student draws a second structure as shown above)".

How would you teach a lesson about the different ways of representing organic molecules to this class?

2. In a diagnostic test a student drew the incorrect structure below.



Given that you have taught your students how to draw structural formulae, how would you conduct a revision lesson, to correct this student's response?

Appendix C: TSPCK rubric for the topic of intervention (Organic Chemistry)

RUBRIC FOR QUANTIFYING PCK – based on Topic Specific Knowledge for Teaching

TSPCK Components	Limited(1)	(2) Basic	(3) Developing	Exemplary (4)
Category A Learner Prior Knowledge including misconceptions	A1: No identification/No acknowledgement/No consideration of student prior knowledge or misconceptions No explanation of concepts	Teacher only acknowledges misconception/prior knowledge. Provides standardized knowledge as definition Repeats standard concepts/definition with no expansion	Teacher acknowledges misconception and provides explanation to confront misconception that has logic Provide standardized knowledge as definition and/or Expands and re-phrase explanation	Teacher acknowledges misconception and provides a correct explanation to confront misconception Provide standardized knowledge as definition and/or Expands and re-phrases explanation
	A2: No identification/No acknowledgement/No consideration of student prior knowledge or misconceptions No explanation of concepts	Teacher only acknowledges misconception/prior knowledge. Provides standardized knowledge as definition Repeats standard concepts/definition with no expansion	Teacher acknowledges misconception and provides explanation to confront misconception that has logic Provide standardized knowledge as definition and/or Expands and re-phrase explanation	Teacher acknowledges misconception and provides a correct explanation to confront misconception Provide standardized knowledge as definition and/or Expands and re-phrases explanation
Category B Curricular Saliency	B1: Only subordinate ideas identified Sequencing no value due to mixed concepts or no sequence provided at all	Identifies at least 1 Big Ideas Sequencing can be followed but has at least one illogical placing of key concepts (Big Ideas). Reasons given for sequence unclear or lacks logic	Identifies at least 2 Big Ideas Provides logical sequence of concepts of at least two Big Ideas, Reasons given are either clear or logical	Identifies at least 3 Big Ideas Provides logical sequence of all three Big Ideas with sound reasons
	B2: Identified subordinate ideas mixed with those Big Ideas of other topics Map lacks logic No linking words	Not all Big Ideas have subordinate concepts identified Some Subordinate concepts used as starting point Linking words absent Some subordinate ideas relate to big ideas	Identifies subordinate ideas and shows links to Big ideas with no linking words Uses at least 2 big ideas as a starting point Subordinate ideas relate to Big ideas on map	Identifies subordinate ideas and explains/shows links Uses all 3 Big ideas as a starting point Subordinate ideas relate to Big ideas on map Cross links shown where applicable
	B3: Identified pre concepts lack coherence with current topics, do not relate to concept map	Identified pre concepts do not relate to concepts to be taught in map Not all identified pre-concepts refer to concepts generally regarded as basic for the subject/ discipline	Most Identified pre concepts relate to concepts to be taught in map Most Identified pre-concepts refer to concepts generally regarded as basic for the subject/ discipline	All Identified pre-concepts refer to concepts generally regarded as basic for the subject/ discipline Identified pre concepts relate to concepts to be taught in map
	B4: Reasons given for importance	Reasons given for importance of	Reasons given for importance of topic	Reasons given for importance of topic include

TSPCK Components	Limited(1)	(2) Basic	(3) Developing	Exemplary (4)
	of topic limited to general benefit of education One reasons given or gives a general statement such as " has important applications)	topic exclude conceptual considerations such as scaffolding/sequential development of understanding for other topics in the subject. But may include application to everyday life	include reference to conceptual considerations such as scaffolding/sequential development of understanding of other topics in the subject (however topics not specified) and application to everyday life	conceptual considerations such as scaffolding/sequential development of understanding for specified other subsequent topics in the subject and application to everyday life and/or intrinsic interest
Category C Understanding of what makes topic easy or difficult to understand	Identifies broad topics without specifying the actual sub-concepts that are problematic Reasons not given to identified concepts	Identifies specific concepts but provides broad /generic reasons such as 'abstract'	Identifies specific concepts with reasons related to prior knowledge of students or common misconceptions	Identifies specific concepts with reasons related to prior knowledge of students or common misconceptions Provides reasons linking to specific gate keeping concepts that when not fully understood adds to the difficulty of a concept regarded as difficult
Category D Representations/ analogies /models	D1: Limited to use of only macroscopic or symbolic representation of scientific notation i.e. formulae/equations	Use of macroscopic representation (analogies, demos, etc.) and Use of scientific symbolic representation for different aspects of a concept not enforcing a specific aspect.	Use of macroscopic representation (analogies, demos, etc.) and/or Use of scientific symbolic representation to enforce a specific aspect of a concept	Use of macroscopic representation (analogies, demos, etc.) and/ or Use of scientific symbolic representation with Use of sub-microscopic representation to enforce a specific aspect of a concept
	D2: No discussion on how the representation is going to be used or suggested use in appropriate, unworkable or unsafe	Discussion lacks logic or clarity List of concepts given with no explanation on how representation is going to be used Suggested procedure impractical	Discussion on how the model shows logic and part of explanation shows conceptual orientation Gives clear or satisfactory explanation on how the chosen representation is going to be used Suggested procedure is workable	Explanation clear, logical and shows conceptual orientation Clearly, explained the procedure how the chosen representation can be used Suggested procedure is workable and takes into consideration learners' context
Category E 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 Lack conceptual orientation	Acknowledges student misconceptions with no corresponding confrontation strategy Lacks aspects of curriculum saliency Use of macroscopic and symbolic and microscopic representations for different aspects of a concept not enforcing a singular aspect of the concept. Parts of the explanation show conceptual orientation	Considers confirmation/confrontation of student prior knowledge and/or common misconceptions Considers at least one aspect related to curriculum saliency: sequencing or emphasis of important conceptual aspects Uses at least two different levels of representations to enforce an aspect of a concept Conceptual orientation to approach	Considers confirmation/confrontation of student prior knowledge and/or common 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 a singular aspect of a concept. Conceptual approach to topic clear

Appendix D: TSPCK rubric for topic of transfer (Organic Chemistry)

TSPCK Components		(1) Limited	(2) Basic	(3) Developing	(4) Exemplary
Learner Prior Knowledge including misconceptions (may be implied)		- Content-based explanation only (correct answer) - No consideration of student prior knowledge or misconceptions	- Identifies misconception or prior knowledge - Provides standardized knowledge as definition	- Identifies misconception or prior knowledge - Provides standardized knowledge as definition - Expands explanation	- Identifies misconception or prior knowledge - Provides standardized knowledge as definition - Expands explanation - Explanation demonstrates conceptual understanding
Section A1 and A2					
Curricular Saliency	B1	Identifies correctly 4 prior concepts with some that are generic (mole and stoichiometry), and provides no reasons for choice; (<i>concepts may not be relevant to the topic</i>) Q1	Identifies correctly 4 prior concepts that are relevant to topic but reasons for choice are generic (<i>may not be related to teaching or scaffolding of learning the topic</i>) Q1	Identifies 4 prior concepts, provides acceptable reasons related to teaching or scaffolding of learning; Q1	Identifies 4 prior concepts, provides detailed and appropriate reasons for choice; Q1
	B2	- Identifies 1 Big Idea from set of concepts provided, may be a mix of big ideas with subordinate ideas Q2 - Provides sequence for teaching the Big Ideas, sequence may not be logical, with no reasons provided - Provides no map/illlogical map of Big Ideas, Q5	- Identifies 2 Big Ideas from set of concepts provided may include subordinate idea, Q2 - Provides sequence for teaching the three Big Ideas, sequence/reasons may not be logical, Q3 & Q4 - Draws a map of Big Ideas, no subordinate concepts. Q5	- Identifies 3 Big Ideas from set of concepts provided, Q2 - Provides logical sequence for teaching the three Big Ideas Q3 - With reasons that are generic Q4 - Draws a map of Big Ideas with some links to subordinate concepts Q5	- Identifies 3 Big Ideas from set of concepts provided, Q2 - Provides logical sequence for teaching the three Big Ideas Q3 - Reasons for sequence related to logical progression, conceptual scaffolding of learning, Q4 - Identifies subordinate concepts and shows links to Big Ideas in form of a logical map, Q5
	B3	- Lists importance of organic chemistry as a topic related to application and/or motivation/interest. - No reasons given Q6	- Identifies Importance of organic chemistry as a topic related to two aspects, application and motivation/interest. - Gives reason for one aspect listed (Q6)	- Importance of organic chemistry as a topic with namely, application and motivation/interest - Reasons related to both aspects Q6	- Importance of organic chemistry as a topic related to all aspects namely conceptual progression, application and motivation/interest - Reasons related to all aspects Q6
Section B					

TSPCK Components		(1) Limited	(2) Basic	(3) Developing	(4) Exemplary
What makes topic difficult to teach		- Identifies broad topics without specifying the actual sub-concepts that are problematic - Reasons not given	- Identifies specific concepts - Provides broad /generic reasons such as 'abstract'	Identifies specific concepts with reasons related to prior knowledge of students or common misconceptions (which may be implied)	- Identifies specific concepts with reasons related to prior knowledge of students or common misconceptions - Provides reasons linking to specific gate keeping concept(s) that when not fully understood adds to the difficulty of a concept regarded as difficult
Section C					
Representations	D1	Describes use of 1/2 of the reps provided (use may not be appropriate)	Describes appropriate use of 3 of the reps provided	Describes an appropriate use of 4 of the reps provided	Describes an appropriate use for 5 representations provided
	D2	- Limited to use of symbolic representation of scientific notation i.e. formulae/equations - No linking of specific concept - Poor link between the choice of representation in part (a) and the use of it emphasizing a specific concept part (c)	- Provides standardized knowledge to define reps - Use of symbolic representation to enforce a specific aspect of a concept - Gives textbook definition to explain the use of a certain representation in emphasizing a specific concept	- Use of representation of a molecule to enforce a specific concept i.e. may link representation to intermolecular forces. (lines drawing more than equations) - Makes link between C chain length and/or surface area to bpt and/or IMF with explanation - States facts but does not mention energy or bpt. explicitly	- Use of macroscopic representation (analogies, models, etc.) / <u>or</u> - Use of scientific symbolic representation - Includes conceptual explanation of factors such as chain length, surface area and links them to explain differences in IMF, energy and bpt.
	D1 = b D2 = a and c				
Teaching Strategies		- Chooses strategy that - Gives only the correct answer to the task - No confirmation/confrontation of student prior knowledge and/or common misconceptions	- Chooses strategy that - Considers confirmation/confrontation of student prior knowledge and/or common misconceptions - Uses only symbolic representation - No conceptual approach	- Chooses strategy that - Considers confirmation/confrontation of student prior knowledge and/or common misconceptions - Conceptual approach to topic not clear - Uses a representation or model of a molecule to enforce an aspect of a concept.	- Chooses strategy that - Considers confirmation/confrontation of student prior knowledge and/or common misconceptions - Uses a <u>model</u> or <u>symbolic</u> representation to enforce a singular aspect of a concept. - Conceptual approach explicit
Section E					
E1 and E2					

Appendix E: Interview Schedule

Section A: Questions about TSPCK components for the topic of transfer

1. What did you consider when formulating responses to the misconceptions in the Learner Prior Knowledge test items?
2. How did you formulate Big Ideas in the test item Curricular Saliency? What helped you to formulate Big Ideas? What helped you to sequence them?
3. How did you choose what you considered difficult to teach in the 'what is difficult test item?
4. How did you choose a representation, and why was it better than the others given?
5. What knowledge did you draw from - in coming up with a conceptual teaching strategy for the last test item?

Section B: Probing questions for mechanism explaining transfer of learnt reasoning in the topic of transfer

1. What sequence in using the five components of TSPCK did you follow when engaging with the new topic?
2. Representations was the easiest component to engage with according to my study for the topic of transfer. You used representations to engage with other component of TSPCK, namely..... It seems that you used Representations 'as a way in' – when having to teach a particular concept, is it easiest to think of representations you might use? If so, what is the link between representations and teaching?
3. Which component was personally most difficult for you?
4. Which component was personally least difficult (easy) for you?
5. Do you think the intervention helped? If so, how did knowledge related to teaching Electrochemistry assist you to teach Organic Chemistry? Did knowledge of TSPCK help you? Elaborate pls.
6. How confident are you now having the TSPCK framework to your disposal? Do you think you could use the TSPCK framework each time you plan to teach a new topic? If so, how would you go about planning using the framework? Is there other knowledge that you might draw from as well? Thanks

Appendix F: Ethics

Appendix F1: Information sheet to pre-service teachers



INFORMATION SHEET FOR PRE-SERVICE TEACHERS

DATE: 10 August 2014

Dear Science Education Graduate

My name is Chris de Jager studying towards a Masters degree in Science Education in the School of Education at the University of the Witwatersrand.

I am conducting research on transfer of Topic-specific Pedagogical CK (TSPCK) from one topic into a new topic. My research involves analysis of completed questionnaires that you completed in the previous year. In order to determine whether transfer of TSPCK occurred, I need to compare the scores of the completed questionnaires for both Electrochemistry and Organic Chemistry. Having done this, I have some questions that I need to ask in order to explore the process that you underwent more deeply. Your contribution during the interview will assist me in determining a possible mechanism for transfer of TSPCK.

While your consent in completing the quantitative TSPCK instruments was sought previously as part of the larger study, I hereby request it again for analysis and for a further audio recorded interview. The interviews will take place at the Education Campus of Witwatersrand University. You do not have to answer a specific question during the interview, if you wish not to. In order to analyse the interview data, all dialogue during the interview will be audiotaped. All audiotapes will be transcribed in order to look for any patterns among the different interviews. If you are not willing to be audiotaped, you can indicate this and the interview will not be audiotaped. Your name and identity will be kept confidential at all times and in all academic writing about the study. Your individual privacy will be maintained by using pseudonyms if a need

to refer to a particular quote arises in all published and written data resulting from the study. All research data will be destroyed after 3 years after completion of the project.

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

Please let me know if you require any further information.

Thank you very much for your help.

Yours sincerely,



SIGNATURE:

NAME: Chris de Jager

ADDRESS: 21 St. Georges Road, Bedfordview, JHB, 2008.

EMAIL: cfdejager@gmail.com

TELEPHONE NUMBERS: cell: 084 591 8162

Appendix F2: Informed consent form**PRE-SERVICE TEACHER CONSENT FORM****Teacher Consent Form**

Please fill in the reply slip below if you agree to participate in my study called:
Investigating a mechanism for transfer of topic-specific pedagogical content
knowledge in a new chemistry topic.

My name is: _____

Permission for interview

I agree to participate in the interview as requested **YES/NO**

I have given permission that my previously completed questionnaires
may be scored and analysed. **YES/NO**

I'm aware that interview questions might refer to answers given
by me previously in both the completed Electrochemistry
and Organic Chemistry questionnaires. **YES/NO**

I know that Chris de Jager will keep my information confidential
and safe and that my name not be revealed. **YES/NO**

I know that I do not have to answer every question and can withdraw
from the study at any time. **YES/NO**

I know that I can ask not to be audiotaped. **YES/NO**

I know that all the data collected during this study will be destroyed
within 3-5 years after completion of my project. **YES/NO**

Sign _____ Date _____

Appendix F3: Ethic Clearance Certificate

Wits School of Education

27 St Andrews Road, Parktown, Johannesburg, 2193 • Private Bag 3, Wits 2050, South Africa
Tel: +27 11 717-3007 • Fax: +27 11 717-3009 • Website: www.wits.ac.za



31 October 2014

Dear Mr De Jager

I have great pleasure in granting you permission to conduct your research:

with Ethics protocol number: **Investigating a mechanism for transfer of topic specific pedagogical content knowledge in a new chemistry topic**

With Ethics protocol number: 2014ECE045M

in the Wits School of Education in 2014-2015

I wish you the best in your research

Sincerely

Professor Karin Brodie
Deputy Head of School
Cc: Dr Elizabeth Mavhunga