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Ndlovu, Musawenkosi

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THE DESIGN OF AN INSTRUMENT TO MEASURE PHYSICAL SCIENCE TEACHERS' TOPIC SPECIFIC PEDAGOGICAL CONTENT KNOWLEDGE IN ELECTROCHEMISTRY

A research project submitted to the

Faculty of Science, University of the Witwatersrand

By

Musawenkosi Ndlovu

In

Partial fulfilment of the requirements for degree of

Master of Science (Science Education).

(Protocol Number: 2012ECE117**C**)

Supervisors

Professor Marissa Rollnick

Dr. Elizabeth Mavhunga

Johannesburg, 2014

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Date

Musawenkosi Ndlovu

Abstract

Research has ranked electrochemistry as one of the more difficult topics to teach and learn. Examiners in South Africa have complained about the poor performance in electrochemistry related concepts in Grade 12 public exams. This may suggest that the physical science teachers may not be teaching it very well. Accomplished teachers use specialized knowledge to transform their knowledge of subject matter into a form that can easily be understood by learners, known as pedagogical content knowledge (PCK). Little is known about the quality of PCK of teachers within this topic and currently there is no instrument to measure quality of topic specific PCK of practicing physical science teachers. The main purpose of the study was to design and validate an instrument that could be used to measure the quality of topic specific PCK of practicing physical science teachers in electrochemistry. The study was a methodology study which used a Mixed Methods (MM) approach. MM were used because the design of the instrument requires both qualitative and quantitative methods in the various steps towards its creation. The topic specific PCK (TSPCK) theoretical framework guided the design of the instrument. TSPCK comprises of 5 components namely: (i) Learners' Prior Knowledge including misconceptions; (ii) Curricular Saliency; (iii) What makes topic easy or difficult to understand; (iv) Representations or models; and (v) Conceptual teaching Strategies that enables transformation of content knowledge into its teachability. The new instrument was designed to elucidate TSPCK in electrochemistry according to these five components which each component represented a test item. The design process followed these steps chronologically: (i) Conceptualization of test items, (ii) construction of the instrument and judgment of items, (iii) piloting and construction of the actual instrument and finally validation of the instrument. After its conceptualization and development, the instrument was validated with a convenience sample of 21 practicing physical science teachers in Johannesburg schools, Gauteng province, South Africa. A topic specific PCK rubric was used to score the teachers' responses on a 4 point scale-from 1 "limited" to 4 "Exemplary" Topic Specific PCK. The Rasch Winsteps program analysed the teachers' scores and ascertained the validity of the instrument through statistics of goodness of fit. In addition, the Rasch model determined the hierarchy difficulty of topic specific PCK components as well as instrument reliability. Both the items and persons' responses fell within an acceptable conventional range of -2 and +2 *Infit/outfit* statistics. The item and person reliability indices of the developed instrument were 0.97 and 0.89 respectively. The results show that it is possible to design an instrument that is valid and reliable instrument. Data on content knowledge of teachers was collected using the Content Knowledge test. It was found

that a high concentration of teachers possessed a sound knowledge of electrochemistry but with a corresponding low topic specific PCK. This is likely the reason of poor performance of grade 12 learners in exams on electrochemistry related topics. Furthermore, a positive statistically significant linear relationship was found to exist between Content knowledge and the measured teachers' topic specific PCK. The findings suggest that TSPCK instrument might be used for teaching purposes so as to boost the practicing teachers' TSPCK on electrochemistry. In addition, the findings suggest that the instrument might be incorporated as a training tool in in-service teacher workshops.

Keywords: electrochemistry, practicing teachers' topic specific pedagogical content knowledge

Dedication

To myself and to the sleepless nights as well as weekends I had to study. To my children: Shannon, Shayne, Sharleen, Shelton, to my nephew Edwin and my niece Mbalenhle: All were supportive throughout this study. To my parents: Laizah and Steerford who inculcated in me the values of good education.

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List of Acronyms

ACE	Advanced Certificate in Education
ACER	Australian Council for Educational Research
CK	Content knowledge
CASS	Continuous assessment
CoRes	Content Representations
DBE	Department of Basic Education
FET	Further Education and Training
MM	Mixed methods
NCS	National Curriculum Statement
NSC	National Senior Certificate
PaP-eRs	Pedagogical and Professional-experience Repertoires
PCKg	Pedagogical content of knowing
PCK	Pedagogical content knowledge
SBA	School based assessment
SMK	Subject matter knowledge
SSIP	Secondary schools intervention programme
TSPCK	Topic Specific pedagogical content knowledge

Chapter 1

INTRODUCTION TO THE STUDY

1.0 Introduction

Electrochemistry is considered by some teachers to be a difficult chemistry topic to teach because of its abstract nature (Butt & Smith, 1987; Gannett & Treagust, 1992a; Sanger & Greenbowe, 1997). Complaints by grade 12 examiners on poor learner performance in public exams provide evidence that teachers do not teach electrochemistry well. As a way of teaching for understanding, expert teachers use specialized knowledge to transform their knowledge of the subject matter into a form that can easily be understood by learners, known as pedagogical content knowledge (PCK). PCK, as defined by Shulman (1986), is the special unique knowledge used by teachers to transform subject matter into teachable form. However this knowledge is hidden within teachers' minds and there is debate about a common uniform understanding of its nature. One reason for this debate nature could be due to lack of concrete examples of teachers' PCK (Loughran, Mulhall, & Berry, 2004). There is also a paucity of instruments in the literature for measuring the quality of PCK. Therefore this study aims to develop and validate an instrument for measurement of PCK within electrochemistry.

1.1 Problem statement

As a science subject marker of grade 12 exams, I have found that learners in grade 12 have difficulties in understanding the concepts, and answering questions in applied electrochemistry because they do not observe the 'rules of the game' as argued by Sanger and Greenbowe (1997). This suggests possibly that teachers may not teach it effectively for conceptual understanding. Teaching for conceptual understanding is linked to PCK. The quality of PCK particularly in electrochemistry in physical science teachers in Gauteng is not known. PCK within a specific topic is called Topic Specific PCK. It is different from the generic PCK as it focuses on the transformation of the understanding of content of a particular topic only. According to

Mavhunga and Rollnick (2013) Topic Specific PCK for each topic is different and specific to that topic since the teacher uses careful reasoning and specific considerations to teach a certain topic. Therefore, there is a need for an instrument to measure the quality of Topic Specific PCK of physical science teachers with respect to electrochemistry. In response to this need, this study seeks to develop and validate such an instrument. I have elaborated on this difference in the literature review below.

1.2 Rationale

This project stems from previous research (Rollnick, Bennett, Rhemtula, Dharsey & Ndlovu, 2008; Davidowitz & Rollnick, 2011) on how content knowledge influences the way a teacher would teach particular concepts to learners in different learning contexts. Electrochemistry is one of the major topics to be covered in the grade 12 National Curriculum in South Africa. It also relates to learners' daily life as it is used in purification processes and the battery industry, so it is important that learners are taught concepts on the topic. However, It is indicated above that electrochemistry is a complex, abstract topic that is difficult for teachers to teach and for learners to learn. It is also reported (Department of Basic Education [DBE], 2011, 2012) that learners often hold common misconceptions such as the aspect of the sign assigned to the electrodes in galvanic and electrolytic cells and oxidation and reduction processes. In South Africa, this perception is supported by the observed poor performance of grade 12 learners on questions related to the topic in the final national examination 2011 (DBE, 2011). Evidence of this is displayed on Table 2.2 and Table 2.3 respectively on section 2.6. A secondary school intervention programme (SSIP) for grade 12 has been running from January to September during weekends and holidays each year since 2010 as an initiative by the government to improve the pass rates of physical science and mathematics in the National Senior Certificate (NSC) examination. Despite this effort, the performance of learners in physical sciences is still poor and reports year after year indicate poor performance in questions related to electrochemistry (DBE, 2011; 2012). Evidence of poor performance is displayed in table.

Table 1.1: Number of learners who passed physical sciences in NSC from 2009-2012 (adapted from DBE, 2011, 2012)

Year	Number Wrote	Number achieved 30% & above	% achieved at 30% & above	Number achieved at 40% & above	% achieved at 40% & above
2009	220 882	81 356	36.8%	45 452	20.6%
2010	205 364	98 260	47.8%	60 917	29.7%
2011	180 585	96 441	53.4%	61 109	33.8%
2012	178 887	109 700	61.3%	69 927	39.1%

Table 1.1 shows that the learners perform poorly in physical sciences as the number of those who score more than 40% remains fairly low. Within physical sciences, performance on electrochemistry remains poor since electrochemistry is part of physical sciences. Poor performance in electrochemistry could have a profound effect on lowering the percentage pass rate on physical sciences as electrochemistry forms about 40% of the grade 12 question chemistry papers (see section 2.6 for specific details). Therefore, there is a need to explore how teachers think about and teach the topic of electrochemistry in class as it is part of physical sciences. Kriek and Grayson had blamed this on the state of mathematics and science education in South Africa which they felt it was a cause for concern. They went on to say that professional attitudes of teachers have a bearing on this low achievement. These researchers cited ill preparedness of teachers and omitting sections they do not understanding as some of these major unprofessional attitudes. Maybe this could be a reason why electrochemistry questions are answered poorly the teachers may be rushing through the topic or omitting certain sections as it is the last chapter in the chemistry curriculum. This indirectly implies that the poor results by learners in grade 12 NSC examination could be a result of poor teaching (poor pedagogical strategies), poor content knowledge or lack of understanding of electrochemistry concepts by teachers due to their abstractness.

Access to such information may be achieved through investigating teachers understanding of the importance of a topic within a curriculum and to the lives of students, as well as learning difficulties such as misconceptions held by learners, representations used in teaching and teaching strategies. These aspects are considered as part of the knowledge considered by teachers who have PCK in a given topic (Geddis & Wood, 1997). However, the current status of the knowledge of teachers in South Africa with respect to the aspects above with reference to the topic of electrochemistry is not known. Therefore, it is important to establish their current status so as to inform teacher support programmes or teacher in-service interventions programmes. Thus, a PCK measuring instrument that considers these aspects in its epistemology is of interest to the study. Thus this study will provide such an assessment instrument within the topic of electrochemistry. The teacher development programmes might design teacher training programmes specific to such topics to help teachers improve the delivery of concept in a manner that would facilitate conceptual understanding of the topic (electrochemistry). The findings of this study could also provide new information on how the professional knowledge of teachers affects the learners' understanding of the topic on electrochemistry as well as their possible errors in the teaching of this topic. My work will provide the missing diagnostic information on how teacher content knowledge in electrochemistry relates to their understanding of its teachability.

1.3 Aims of the study

The aims of the study were:

- To design and validate a topic specific instrument to measure the quality of physical science teachers' topic specific PCK in electrochemistry
- To measure the quality of PCK of the physical science teachers using the developed TSPCK instrument
- To measure the content knowledge of these teachers using a Content Knowledge electrochemistry achievement test.

- To explore the relationship between the measured quality of Topic Specific PCK of the teachers and their content knowledge in electrochemistry.

1.4 Research Questions

The project is guided by the following specific questions:

- How can a valid instrument be designed for measuring the quality of teachers' PCK in electrochemistry?
- How valid is this instrument in measuring the Topic Specific PCK of a sample of experienced teachers in electrochemistry in the Gauteng Province?
- What is the relationship between the measured quality of their Topic Specific PCK of teachers and their content knowledge in electrochemistry?

1.5 The Researcher and Positionality

I am a female born in Zimbabwe, currently residing in the city of Johannesburg, South Africa. My first years of schooling were at a rural school found in a small town called Plumtree-a border town between Botswana and Zimbabwe. I travelled 10km daily to and from a nearby primary school. In the late 70s there was a liberation war between blacks and Whites which led to closure of most rural schools. This was a blow to my education as I was in the third grade during that time and I stayed for 1 year without schooling. As that was not enough, my parents divorced before I started schooling which forced my mother to go to a nearby city-Bulawayo to seek for employment. She worked as a baby minder for her younger sister-a job with a very little salary. My mother was forced to look for an alternative and then she decided to sell clothes as a street hawker at a mine in another province in order to earn a living. Thanks to this venture, she managed to put food on the table. When she learnt that the schools had closed she came to fetch us (me and my other four siblings) from my grandmother and she registered us at a town school. She struggled to pay

our school fees and rent as this business of selling clothes was not bringing sufficient income. I think this is what propelled me do achieve better in school with the intention of helping her in future. Struggling as she was she prioritized education first. On noticing the struggle, my mom was going through to raise us and educate us; my eldest brother dropped out of school in form 2 (grade 9 using South African schooling system) and got a job at a clothing company. He volunteered to make my education his responsibility as a way of helping our mother. He paid my school fees. I completed my secondary education and I had no money to proceed to university to pursue my studies as my brother was earning very little. This forced me to look for a temporary teaching post to raise funds in order to fund my teacher training course in the following years. In early 1990s I was accepted at Hillside Teachers' College where I trained as a science teacher majoring in biology, chemistry and physics. The college focused on both content and pedagogical skills. Emphasis was placed on the use of practical work and representations as way of enhancing conceptual understanding of the concepts. I did my honours degree through distance learning with Zimbabwe Open University.

When I started teaching here in South Africa in 2007, I noticed that physical science teachers mainly focused most on drilling the learners for examinations rather than making them investigate the phenomenon themselves. From my observation I noticed that there were fewer experiments done as most work was done theoretically or just a demonstration by a teacher especially if the work is part of the School based assessment (SBA) also known as continuous assessment (CASS). This left me with this question in mind- Is there a good recipe for teaching? In 2011, I enrolled at Wits University where I was exposed to this idea of Shulman of transforming content knowledge into a teachable form. It is then when I noticed how important the knowledge of teaching was. I then perceived teachers as vehicles of change. I also embrace the Science education tutors and those who have invested their interest in Science education. I hope that my study is a first step towards building teachers who know their goal and purpose in making the learners understand the Science phenomena. I think

what constitutes good teaching is the understanding of the content knowledge in the subject domain. This is reflected in the methodology used in disseminating information to recipients and as well in the teaching strategies used. This idea helped me during interactions with my participants and data. This was successful as I had a coherent content knowledge of the topic in question. This allowed me to be flexible in using a combination of data collecting instruments to create multiple data sources. This then called for verification of data through triangulation of opinions. To achieve this I was constantly in consultations with the experts in science education. This minimized bias in the whole research process as the process of designing the instrument was transparent and all stakeholders were involved.

1.6 An outline of research chapters

The following outline of chapters is used to report the study:-

Chapter one locates the study in the context of South Africa by giving: the back ground of the study, problem statement, research questions and the rationale for carrying out this study. Also the researcher and her positionality as well as the structure of my research are presented towards the end.

Chapter Two presents a review of literature related to the major themes of this study and the theoretical framework guiding this study. Reviewed literature is about teachers' PCK and its relationship with content knowledge, empirical studies on PCK, available instruments to measure PCK and their shortfalls in measuring the quality of topic specific PCK of practicing teachers in this study. The chapter ends with a review of misconceptions and difficulties in electrochemistry in general as well as those specific to South African learners.

The main focus of **Chapter Three** is on the research methodology used in this study. This includes the mixed method research design, the selection of participants, instruments used to collect data, data analysis methods,

issues of validity and reliability of instrument and ethical considerations. Limitations of the study is discussed as well

Chapter four focuses on the process followed in the development of the instrument in an attempt to answer research question one. The pilot study is described as well. The chapter ends by describing the adaptation, modification, and piloting of content knowledge achievement test.

Chapter five presents the processes followed in the validation of the instrument, data analysis techniques and procedure used to establish validity and reliability of the instrument. This chapter answers research question two.

Chapter six focuses on the results obtained about the content knowledge of teachers and methods used to find if there is a correlation between the teachers' content knowledge and their topic specific pedagogical content knowledge. Data is analysed both qualitatively and quantitatively. This chapter serves to answer research question 3.

Chapter seven provides a summary of the study, answers to the research questions, and then discusses the finding alongside with the implications. The conclusions are drawn upon which recommendations are made. Critical reflections of the study are highlighted as well. The chapter ends by presenting the limitation of the study.

Chapter 2

Literature Review

The chapter examines literature related to measurement of PCK and topic specific PCK of teachers, to instruments used. This chapter also provides an overview of the framework guiding the design of the instrument and rationale why this theoretical frame work is suitable for my study. Firstly, I begin by looking at pedagogical content knowledge and its portrayal, followed by discussing the tailored model from which the theoretical framework that guided my study is premised. Literature on available instruments to capture topic specific pedagogical content knowledge as well as content knowledge and its relationship with PCK is reviewed in that order. Lastly, I discuss the common misconceptions and difficulties in electrochemistry.

2.1 Introduction

Poor performance of learners in physical science and mathematics in South Africa has been linked to teachers' inadequate or poor content knowledge, their less effective teaching strategies as well as the teachers' unprofessional attitudes (Kriek & Grayson, 2009). Research by Shulman (1986) has shown that good content knowledge only and good pedagogical strategies alone are not sufficient in making subject matter accessible to learners, he identified pedagogical content knowledge (PCK) as the most important attribute. Since then there was this growing belief that a high level of PCK can make a considerable impact on the quality of teaching consequently on the quality of learning experience in most classroom environments (Grossman, 1990; Park, Jan, Chen, & Jung, 2011). For this reason extensive research on PCK has been carried out to find the components of PCK and how they are related. We have also seen researchers coming with different models as an attempt to capture and portray PCK (see section 2.2.3).

Studies that came thereafter proclaimed that the PCK construct is specific to specific topics (van Driel, Verloop & De Vos, 1998; Loughran *et al.,* 2004). Recently, we have seen a growing interest in the studies aimed at

investigating the topic specificity of PCK and measuring its quality. Previous studies were aimed at finding out how teachers transform CK of individual or different topics into PCK for teaching them (van Driel *et al.,* 1998; Abell, 2008). This study will focus on the transformation of the topic of electrochemistry as little is known about any study of this nature undertaken here in South Africa.

Previous research has identified misconceptions and difficulties that students have in electrochemistry (Garnett & Treagust, 1992; Ogude & Bradley, 1994; Sanger & Greenbowe, 1997), in radioactivity (Nakiboğlu & Tekin, 2006) and it has been shown that these misconceptions are legacies of their teachers (e.g. Ogude & Bradley, 1994). No research has diagnosed these in practicing teachers. This missing diagnostics has sparked a wide interest in research aimed at developing instrument to measure PCK within topics and subjects (see section 2.4). Studies to develop instruments to measure topic specific PCK of either pre-service or practicing physical science teachers in chemistry have just become popular e.g. Ozden and Eilks (2011) on chemical reactions; Mavhunga and Rollnick (2013) in chemical equilibrium; Aydeniz and Kirbulut (2012) in electrochemistry, Aydin (2012) in electrochemistry and radioactivity. It has been shown is section 1.3 that there is paucity of these instruments and there is none for measuring electrochemistry for South African practicing teachers specifically. Therefore, the current study has a dual purpose: (i) to design and validate such an instrument and (ii) to measure the content knowledge (CK) of these teachers. By knowing the teachers' content knowledge in the topic on electrochemistry, insights would be gained on whether it is lack of or poor subject matter knowledge or their teaching skills that contribute to low achievement of learners in public examinations as alluded to in the previous section. The teachers may develop better teaching strategies or learn from experienced teachers if they find that their current methods are not sufficient in addressing learners' difficulties in electrochemistry.

2.2 Pedagogical Content Knowledge

Transformation of subject matter knowledge has been a concern for researchers following Shulman's writing on the topic (1986, 1987). Previous teacher training programs and research concentrated on pedagogy or content knowledge only and neglected how this knowledge is transformed into a usable form by teachers (Shulman, 1986). This then prompted Shulman to argue for Pedagogical Content Knowledge (PCK) which he contends is a blend of content knowledge and pedagogical knowledge. He further suggested that it may serve as the unique knowledge possessed by teachers that contributes to effective learning and teaching. According to Shulman (1986, 1987) content knowledge (CK) together with pedagogy informs teachers' instruction. In his 1986 paper, Shulman identified three categories of content knowledge namely: subject matter knowledge, pedagogical content knowledge (PCK) and curricular knowledge as knowledge domains of a teacher, in which PCK is central. PCK is the type of knowledge that relates content knowledge to its teachability and it includes; "*the most useful forms of representations 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). Furthermore, Shulman asserts that PCK also includes an understanding of what makes the learning of specific topics easy or difficult and the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons (Shulman, 1986, p.7). In order to understand the demands for specific topics such as electrochemistry, a teacher should have knowledge of all related concepts in a topic and how they are interlinked, what makes the topic difficult to teach and learn and probably devise strategies that could help him/her convey these abstract concepts to learners in such a manner that the learners will comprehend.

PCK is the kind of teacher knowledge that allows the teacher to know how to teach content, sequence topics and make decisions on choice of strategies

s/he uses in the classroom situation at that point in time (e.g. use of graphs or models). Authors like Verloop and de Vos (1998) preferred to define PCK as the wisdom of practice since they argue that PCK develops over time and this is the combination of teachers' experience acquired in the schools s/he worked in, under different environments and contexts, with the different learners from different cultural backgrounds and with different learning abilities. This implies that teachers use PCK to design and organize lessons as well as for choosing and preparing content for learners. PCK is a very useful construct for effective teaching, but the problem is that a teacher does not know if s/he possesses PCK or not.

2.2.1 Models of PCK

After Shulman'scontribution, the past 25 years have seen researchers trying to characterise and conceptualise PCK and various theoretical models were developed to elucidate PCK as it is tacit and elusive in Kind's (2009) view. Some examples of models and their components are tabulated below, see Table 2.1.

Table 2.1: Different models of PCK as seen by some scholars (adapted from van Driel et al., 1998)

	Subject Matter	**Student learning difficulties**	**Representations Teaching strategies**	**Orientations**	**Curricular knowledge**	**General Pedagogy**	**Assessment**	**Leaning Context**
Shulman (1987)	A	PCK	PCK	A	PCK	PCK	A	A
Grossman(1990)	A	PCK	PCK	A	A	A	A	A
Cochran *et al*. (1993)	PCKg		Nd	Nd	PCKg	PCKg	Nd	PCKg
Veal & MaKinster (1999)	PCK	PCK	PCK	PCK	PCK	PCK	PCK	PCK
Rollnick *et al*. (2008)	PCK		M	Nd	PCK	PCK	M	PCK

Key-'**A**' shows category which is not part of PCK. 'PCK'– part of PCK '**M'** manifestations of teacher Knowledge, '**Nd**'-not discussed explicitly. 'PCKg'-Pedagogical content of knowing.

Table 2.1 shows the different views of the selected scholars about the constituents of PCK. I chose these researchers because all their views if put together they form part of Rollnick *et al.*'s model (2008) from which the topic specific PCK model I intend to use to design the instrument is premised on.

What is striking about the Rollnick *et al.* (2008) model is the fact that it identifies Content (Subject Matter) Knowledge as one of its main teacher knowledge domain and this is one dimension of my study. I am going to use the term CK in this study synonymously with SMK. The next section discusses the model I found more relevant to this study.

2.2.2 The Tailored Model

Because of the tacit nature of PCK, several models have been in use to track how pure content knowledge is transformed to subject matter knowledge for teaching as apparent in the classroom. However, the model that I found appealing and to be fruitful in this study is that of Rollnick *et al.* (2008, see Fig. 2.1) because it shows how teacher's knowledge about the subject, learners and context and pedagogical skills are integrated to form products seen in the classroom referred to as manifestations by Rollnick *et al.* (2008), see Fig. 2.1.

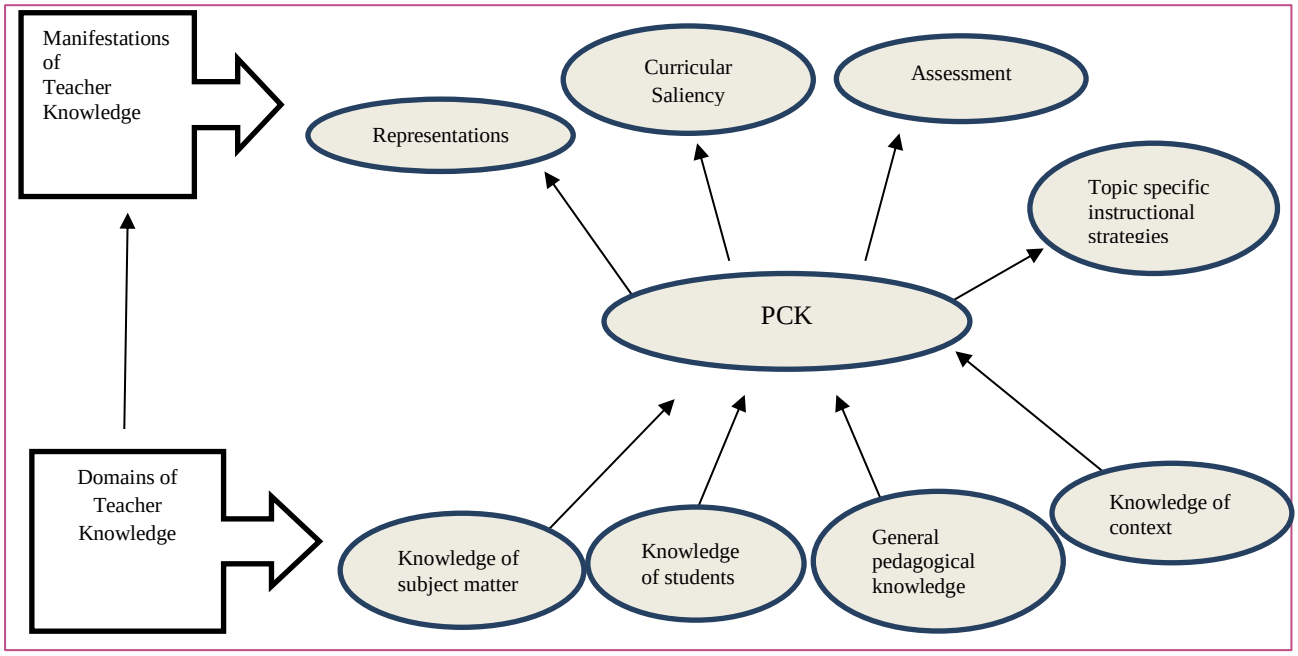


Figure 2.1: A Tailored model from Rollnick *et al.* (2008)

This model separates the teacher's thinking and what s/he does in the classroom situation. The teacher uses integrated knowledge components for planning for an instruction e.g. to replace misconceptions with correct concepts and which representations to use to help learners understand difficult concepts. Other manifestations include knowledge of curriculum and topic specific strategies exemplified by the way a teacher sequences topics and gives assessment to learners based on what is expected in the public examination with regard to electrochemistry. By knowing, the content teachers may devise strategies to teach science under whatever environmental using the limited resources that exist. The teacher becomes very creative if s/he knows the subject. Rollnick *et al.* (2008) assert that good CK is an essential precursor of good PCK. This means that the teacher may become more flexible in terms of his/ her teaching approaches they use in classrooms teaching to accommodate individual learners. Teachers become confident in the subject delivery since they use a combination of their general pedagogical knowledge with understanding of learners as well as CK to produce subject matter knowledge for teaching that is communicated to others. Hence, this study attempts to find out how physical science teachers transform CK to the one understood by learners.

2.2.2.1 Linking the Tailored Model and the Topic Specific PCK Model

In my view, subject matter knowledge is important along with student contexts and the understanding of students' knowledge in the developing of PCK. Therefore, for this study I found the tailored model of PCK (Rollnick *et al.*, 2008) to be a suitable starting point to guide the designing of the topic specific instrument. The model is divided into two parts; the knowledge domains and the products of teacher knowledge all contributing to development of a science professional. From the model it is clear that PCK is blend of CK, knowledge of students and their learning context and general pedagogical knowledge. Rollnick and her colleagues claim that once a teacher has developed PCK, the teacher would be able to solve the dilemma for covering the syllabus as s/he knows which topics are relevant to the

whole syllabus (Curriculum Saliency), when to assess and what to assess and how to assess (assessment knowledge), which alternative strategies can use to clarify or simplify concepts to the level understood by learners (representations), which instructional strategies to use in teaching a specific topic (instructional strategies). The arrows in the Rollnick *et al.* (2008) model show the flow of practice, the lower arrows show what builds PCK and upper arrows emphasis products (what arises from the constructed PCK) which Rollnick and her colleagues call manifestations. In short, PCK would affect the way teachers assess, represent the content and in turn the knowledge of subject affect PCK. PCK is made up collectively from the teachers' knowledge of the subject, the learners' needs and curricular knowledge (referred to as Curricular Saliency in the Topic Specific PCK model). I believe if one component is removed, the whole purpose of teaching science would be defeated. The model is transformative and indicates that CK is central in PCK development.

As mentioned above the Topic Specific PCK model is derived from the Tailored model, the components listed as for *manifestations* of teacher knowledge in Rollnick *et al.* (2008) model are listed as for *transformation* of Content knowledge in the Topic specific PCK model I intend to use in this study (See fig. 2.2). Also it is important to note that these components are a product in the Tailored model while in the Topic Specific PCK model, they are an *input*. However, it worth mentioning that the assessment component listed in the manifestations is not part of the inputs in the Topic Specific PCK model instead a new component "What is difficult or easy to teach" in a topic has been added under inputs as wells as students prior knowledge.

2.3 Theoretical Framework: Topic Specific PCK

According to Bucat (2005),

"There *is a vast difference between knowing about a topic (content knowledge) and knowledge about the teaching and learning of that topic (pedagogical content knowledge)…* " (p. 2).

This implies that PCK is specific for specific topics (Veal & MaKinster, 1999). A teacher develops and accumulates knowledge of teaching a particular topic in a certain way that is unique to the concept being taught (Hashweh, 2005). Veal and MaKinster (1999) point out that common topics in different domains are taught differently within these different subjects and the teaching strategies, representations and demonstrations used also differ from subject to subject (e.g. temperature is a common concept in both chemistry and physics). It implies that the strategies you use in teaching temperature in chemistry would be different from those you use when dealing with temperature in physics and at the same time differ from teachers teaching the same specific topic. Aydin (2012) confirms this in his study in Turkey with two experienced chemistry teachers in the topics electrochemistry and radioactivity. Aydin found that two types of PCK were in existence: these were PCK A for teaching electrochemistry and PCK B for teaching radioactivity. Furthermore, the researcher noticed that PCK A and PCK B were different in the sense that PCK A was teacher centred and had many linkages with other topics from chemistry and physics while PCK B was more or less teacher-centred and had very limited linkages with other topics. van Driel and his colleagues studied topic specific PCK among chemistry teachers in teacher training programmes (van Driel, Verloop, & de Vos, 1998; van Driel, de Jong, & Verloop, 2002). Their studies confirm that teachers develop and use knowledge for teaching specific topics. Other researchers also agreed with topic specific nature of science teachers in high schools to isolate specific concepts for presentation in electrochemistry.

Ball, Thames, & Phelps (2008, p.400) noted that when teaching specific topics, experienced teachers require more than knowing content and how to teach it but also require an understanding of how to teach a particular

topic in another location other than teaching environment. This knowledge includes the understanding students' preconceptions and misconception about the actual topic; identifying main concepts in a topic, choosing a specific strategy to explain or analogies to enhance understanding of that specific topic by learners. The authors viewed this kind of additional knowledge as 'specialized content knowledge' in mathematics while in science, Geddis and Wood (1997) identified it as different kinds of PCK knowledge yet Mavhunga and Rollnick (2011) called it Topic Specific PCK (TSPCK). Furthermore, Ball and her colleagues suggested that researchers need to study teacher knowledge within these science topic-specific contexts and this is the main focus of this study to measure such topic specific knowledge in electrochemistry.

Mavhunga and Rollnick (2011) proposed the construct of topic specific PCK related to Ball *et al.*'s specialized content knowledge of teaching (see Ball *et al.*, 2008) to explain the type of knowledge a teacher uses to transform content knowledge in a particular topic in classroom situations. Mavhunga and Rollnick maintain that the theoretical framework, at the level of topic specific PCK put more emphasis on transformation of the content of the individual topics, instead of the interaction of content and pedagogical knowledge as in PCK proposed by Shulman. TSPCK (according to Mavhunga & Rollnick, 2013) is the *unique knowledge about the content of a given topic that expert teachers use to transform their understanding of the topic into forms that are understood by learners.*The TSPCK model (Fig. 2.2) shows the components and their relationships (Mavhunga & Rollnick, 2013).

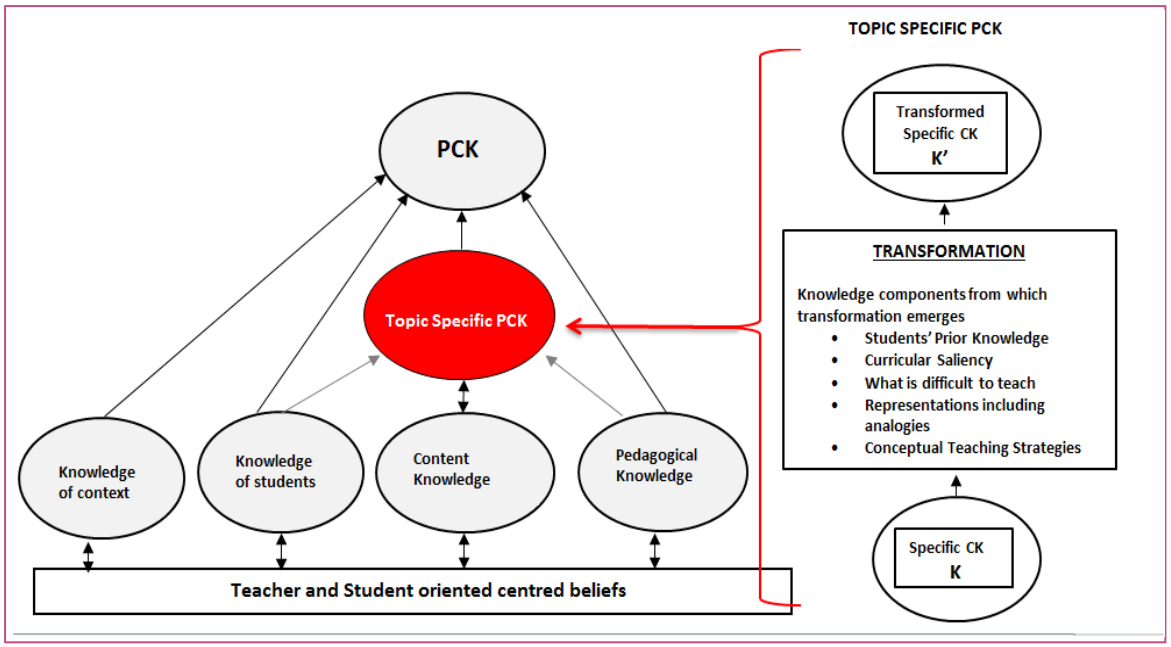


Figure 2.2: Topic Specific PCK model linked to PCK model (adapted from Rollnick *et al.*, 2008, see Fig 2.1).

The authors identified the following as components of TSPCK:

(i) Learners' Prior Knowledge on a given topic: refers to understanding the preconceptions and misconceptions which the learners bring into learning environment influenced by their communities and also learning difficulties.

(ii) Curricular Saliency: deciding what is important for teaching and sequencing.

(iii) Understanding of what makes topic easy or difficult to understand: The learning difficulties are the scientific conceptions about new topic or misconceptions which learners bring into class as a result of interactions within their immediate environment which may hinder grasping of the intended concept or anything that may hinder the child's learning such as non-conducive learning environment, indiscipline, and lack of resources and crowding.

(iv) Representations: refers to graphs, equations, symbolic, sub microscopic and macroscopic representation used during teaching. Some forms of representation are only possible in small classes if the learners are to benefit. A teacher with good knowledge of s/her learners' coupled with good CK will be aware and use these in combination to cater for individual learner needs.

(v) Teaching strategies: these are methods used by teacher to enable understanding of concepts such as models, simulations, graphs, analogues, work sheets and explanation given by the teacher. These strategies should not be just procedural but should promote.

According to Mavhunga and Rollnick (2013), the topic specific PCK for each topic is different and specific to that topic since the teacher uses certain specific components of PCK to reason out as s/he teaches a certain topic. The idea of topic specific PCK is derived from the understanding that transformation of CK is cornerstone in formation PCK. Teachers with high quality PCK were found to transform each topic in a certain manner and could even give grounds for its teaching (Shulman, 1987) because they use specific components of PCK, to think through the specific topic. Thus, this study uses topic specific PCK as a theoretical framework to guide the design the instrument.

2.4 Capturing and Measuring PCK

Attempts have been made to measure, capture and portray PCK notably by Loughran, Berry and Mulhall (2006), Bertram and Loughran (2011) and in South Africa by Rollnick *et al.* (2008) but there is still uncertainty among researchers on what exactly they are measuring. The reason for this is that PCK is tacit, unique to teachers and the teachers do not know whether they use PCK or not and may be uncertain whether they have developed adequate PCK or not. Probably, this could be the reason why van Driel and his colleagues (1998) defined it as the accumulation of wisdom over time

while Grimmet and MacKinnon (1992) cited in van Driel (2002) viewed it as craft knowledge.

2.4.1 Capturing PCK

Loughran *et al.* (2006) and Bertram and Loughran(2011) developed Content Representations or CoRes (a topic specific tool used to capture and portray teacher's PCK and reasoning) and corresponding Pedagogical and Professional-experience Repertoires (PaP-eRs) which give an outline of what a teacher is thinking as s/he prepares for the lesson, how s/he is going to teach "big ideas. "Cores are important because PCK is regarded as tacit and difficult to clarify so they may help deepen the understanding of the complex nature teaching profession and reveal knowledge teachers use in teaching a specific topic, in this case electrochemistry. Although these attempts to capture PCK have been made their quality remains uncertain and hence the solution lies in the proposed topic specific PCK instrument I designed as it has parameters and scales that could be reliable in measuring PCK in the level of a specific topic.

Literature indicates that tools for assessing the quality of PC K both general (e.g. Lee, Luft, & Roehrig, 2007) and topic specific (e.g. Riese & Reinhold, 2009) have been developed. Quite a number of tools have been developed in mathematics; however, development of such tools in science is still at an early stage but has recently gathered momentum. In recent studies, quantitative instruments were developed from teacher tasks, for instance in mathematics (Riese & Reinhold, 2009), in science (Park *et al.,* 2011) and in technology education (Rohaan, Taconis, & Jochems, 2009). Mavhunga and Rollnick (2011) have developed a tool to measure Topic Specific PCK of pre service teachers in chemical equilibrium. This study, therefore, builds on this work to develop a unique tool, a topic specific instrument to measure PCK of teachers of electrochemistry. This tool is unique in the sense that currently a quantitative tool in this topic is non-existent. The developed tool may be used to measure the quality of high school teachers' PCK on teaching a specific topic in chemistry in South Africa that could be shared with novice teachers as there have been few initiatives in South Africa to

measure topic specific PCK. Documenting the quality of topic specific PCK of practicing teachers would help preserve loss of expertise gained by competent physical science teachers over their years of teaching. My belief is that the quality of teaching specific topics lies in the understanding of topic specific PCK of teachers themselves and this can only be achieved through development of topic specific instrument to measure such quality. My work is to provide the missing diagnostic information on how teacher content knowledge affects teaching of electrochemistry and this would help the physical science teachers to reorganize their understanding of science.

2.4.2 Measuring PCK

The tools listed in the literature review are based on different models of PCK. The reason for this observation is partly the lack of agreement in the science education community that still exists over what exactly is being assessed (Mavhunga & Rollnick, 2013). The instrument by Lee *et al.* (2007) is based on two teacher knowledge components, namely, student learning and instructional strategies. The categories of teacher knowledge selected by the creators of the tool render the tool generic and less sensitive to the idea of enabled pedagogical transformation of CK, at a topic level as required by this study. This makes the tool less appropriate for the topic relatedness of this study. In the last 3 years, however, there has been a steady growth of PCK tools that measures the quality of PCK in specific domains, e.g. Park *et al.* (2011) in science as a school subject, Rohaan *et al.* (2009) in technology education, Jüttner and Neuhaus (2012) in biology, Tepner and Witner (2011) in chemistry, Riese and Reinhold (2009) in physics. These instruments, in their epistemological descriptions have made reference to models of PCK addressing science as a school subject (Magnusson, Krajcik, & Borko, 1999), and thus may be used in application to different subject-domains (chemistry, physics, biology, etc.) within the science subject.

While some of the models have addressed all the teacher knowledge components of PCK in the Magnusson et al. (1999) model e.g. such as that by Park *et al.* (2011), and some only selective components such as that by Tepner and Witner (2011), they remain unsuitable for the purpose of this

study, which is to measure PCK at a level one step deeper at a the topic level. At this level, issues of CK transformation are important. Knowledge components commonly identified (e.g. Geddis & Woods, 1997) as enabling transformation are: learners' prior knowledge, subject matter representations, instructional strategies, curriculum materials and curricular saliency. Curriculum materials and curricular saliency are teacher knowledge domains corresponding to Shulman's knowledge of the curriculum. These knowledge components have been mentioned by various scholars (see Park *et al.,* 2011 and Mavhunga & Rollnick, 2013).

In their study of how an accomplished chemistry lecturer in the South African context uses his PCK to transform the knowledge of chemistry into a teachable form, Davidowitz and Rollnick (2011) list a number of manifestations observable in class when transformation of CK occurs. The authors explored the following manifestations: Representations, Topic Specific Strategies, and Interaction with students, Explanations, and Curricular Saliency. Park *et al*. (2011) used a well-known instrument called the Reformed Teaching Observation Protocol (RTOP) and developed and validated a PCK rubric to measure the PCK of a teacher. The PCK rubric measures two parameters only namely *Knowledge of students understanding to certain subject matter* (KSU) and *Knowledge of instructional strategies and representations of the subject matter* (KISR) among the five component of the pentagon model of PCK (e.g. see Park & Oliver, 2008). This is not sufficient for my study as I feel that for effective transformation of subject matter knowledge, the teacher needs more than only just two components of teacher knowledge base. A more recent venture in Turkey, Aydeniz and Kirbulut (2012) developed a *Content Secondary Teachers' Scientific Pedagogical Knowledge* (STSPCK) instrument to assess pre-service science teachers' topic specific PCK of electrochemistry. Still this tool is not suitable for my study as the STSPCK has three categories only namely: assessment, curriculum, and instruction and this tool did not consider the knowledge of the learners. In my view, the teachers' knowledge of the subject, learners, context and teaching skills are blended to form the teacher knowledge (PCK). This specialised knowledge includes knowing which topics are problematic

to learners and what makes a/such topic(s) difficult to teach in addition to the instructional strategies and representations used to clarify such concepts. For this reason, I found that PCK at the level of a specific topic is a suitable construct to guide the design of the instrument. Hence, in this study a topic specific PCK theoretical framework (see Mavhunga & Rollnick, 2013) was used.

I align myself with the researchers who see CK together with experience as the determinant of PCK. This means that in addition to knowledge of structure of content the teacher should know how to break up and sequence the concepts such that the learners under his jurisdiction can understand abstract concepts. The instrument I designed has five components that enable transformation of CK (see Fig. 2.2 for details). I believe CK emerges from conceptual teaching strategies used in a classroom environment during an instruction (see Mavhunga & Rollnick, 2011). The Conceptual Teaching Strategies encompasses all the four knowledge components as the teachers has to draw from the knowledge of learners, knowledge of what makes electrochemistry difficult or easy to teach, and decides which concepts to teach at a particular time (Curricular Saliency) and which representations are suitable for a particular concept. Instruction is the vehicle through which effective teaching and learning occurs, that is, it is through instruction where the goals of teaching are realized.

2.5 Content knowledge and Subject matter knowledge

Teacher content knowledge has been found to be crucial for the improvement of teaching and learning by various authors (Ball *et al.*, 2008; Rollnick *et al.*, 2008). According to Shulman (1986, 1987), *Content Knowledge* (CK) includes knowledge of the subject and its organization; this is scientific knowledge that is the keystone in establishing teaching as a profession. Shulman looked at subject matter or content as the science concepts and phenomena acquired from books and learned in disciplinary settings such as in universities and teacher training colleges, and he argued that this knowledge is the same as that of a novice teacher and subject

expert. He contends that SMK includes both science content knowledge and knowledge of science teaching. Many researchers in science education have agreed with Shulman and added that subject matter knowledge is an umbrella term for the following components as summed up by Cochran and Jones (1998, p.708)

i. content knowledge is concerned with the facts and concepts of the subject matter;
ii. substantive knowledge: these are the explanatory structures or paradigms of the field);
iii. syntactic knowledge is concerned with the methods and processes by which new knowledge in the field is generated;
iv. Beliefs about the subject matter (learners' and teachers' feelings about various aspect of the subject matter).

According to Cochran and Jones (1998), SMK is therefore, the knowledge needed in the understanding of the facts, ideas, theorems, scientific definitions, concepts, processes and making connections among them in a subject. Kind (2009) added that SMK requires knowledge of both the substantive structure (facts and their organising principles) and syntactic structure (legitimacy principles for the rules) of a subject domain. Shulman (1986) asserts that *knowing that* and *knowing why* are the two kinds of SMK needed by teachers. He maintains that *knowing that* is the most basic level of SMK while *knowing why* is mainly concerned with understanding why things are as they are and why they happened like that. He contends that the teacher need not only to understand *that* something is so but must also understand *why* it is so (Shulman, 1986: p.9). This implies that in addition to knowing the facts and theorems of the subject matter, the teacher must further understand why such phenomenon occurred. Cochran and Jones (1998) argue that CK pays much attention mainly on the differences in amount and quality of SMK possessed by teachers and thus another focus of my study-hence, the adoption of the term CK in this study.

2.5.1 The Relationship between Content Knowledge and Pedagogical Content Knowledge

Studies to establish the relationship between CK and PCK are available in literature (e.g. see Kind, 2009). In section 2.3 above, CK has been shown as that knowledge about the teaching and also the knowledge of the learning of a specific subject matter including specific learning demands of that subject matter (in this case chemistry). While on one hand, PCK includes the constituent components of knowledge for teaching science in terms of particular topics and grade levels as well as knowledge of science teachers as learners, knowledge of science teacher education curriculum, instruction, and assessment. For a teacher to develop PCK, strong content knowledge is necessary so that they may be able identify learners' pre-conceptions about the topic or problematic topics which they encounter in examinations and in the classroom. If a teacher has adequate content knowledge s/he may notice mistakes that are constantly recurring when s/he responds to oral questions and even during marking of tests and their exercises. Good content knowledge gives a teacher a sense of security and confidence as they plan and teach the learners, which gives a firm foundation for a teacher to develop appropriate PCK (e.g. Childs & McNicholl, 2007; Kind, 2009). Smith and Neale (1989) added that a more coherent CK is necessary for an effective PCK. Researchers maintain that adequate CK enhances confidence in both the teacher (as s/he is able to present data in a logical form and in small packages) and in the learner. Kind (2009) argues that when a teacher has deficient CK, s/he would resort to more passive teaching strategies and also show less understanding of learners' learning difficulties related to the science (p.191). Overconfidence on one hand may result in poor quality of lessons (Kind, 2009) as the teachers is absorbed in displaying how much CK about the topic s/he knows instead of making that CK accessible to learners. Hence, in this study I explored this relationship between CK and PCK.

Various researchers maintain that classroom experience (see Simmons, Emory, Carter, Coker, Finnegan, & Crockett, 1999) and emotional attributes

e.g. confidence (Childs & McNicholl, 2007; Kind, 2009) are crucial in developing PCK while CK is a prerequisite (Rollnick *et al.*, 2008; Park, Jang, Chen, & Jung, 2011). Ogbonnaya (2007) argued that the knowledge of the subject matter possessed by the teacher influences his/her classroom practices or behaviour. By knowing the content, teachers may devise strategies to teach science under whatever environmental conditions using the limited resources they have.

Ball *et al.* (2008) had similar views to Rollnick and colleagues about the centrality of SMK but assert that SMK consists of common content knowledge (CCK) and specialized content knowledge (SCK). In Ball *et al.*'s view SCK is the mathematical knowledge that a teacher uses to engage in particular tasks, explain concepts accurately to learners, and to identify erroneous answers from learners. Common content knowledge is the kind of knowledge that this study seeks to investigate because it is the one that is transformed into CK for teaching. In their empirical case studies carried out in South Africa to determine the effect of CK in two teachers teaching chemical equilibrium and the mole respectively Rollnick *et al.* (2008) affirm that CK is central in the development of PCK. The findings were: in case study one, the two teachers focused on a procedural way of teaching rather teaching for conceptual understanding thus leading to a suggestion that content knowledge might have been lacking in these teachers. In the second case study, it was found that the teacher had detailed CK on the topic and also showed evidence of developed PCK. In this study, I determined how much common content knowledge the teachers possess in order to handle the topic on electrochemistry effectively and this was compared with specialized content knowledge they use for teaching. The proposed instrument measured the quality of this specialized content knowledge. Also the relationship between content knowledge of teachers and PCK was established as there is still doubt about how the two relate to each other.

In this study, topic specific questions on electrochemistry were designed and administered to physical science teachers to check the quality of their topic specific PCK when teaching electrochemistry. This facilitated identification of their strengths and weaknesses in teaching electrochemical cells, Redox

reactions, and identification of electrodes given half-cell reactions. This in turn would help design in-service teacher training programmes specific to such topics to help teachers improve the delivery of concept in a manner that would facilitate conceptual understanding of the topic (electrochemistry). This information may also be beneficial in revamping content preparation and informing policies about certification of teachers.

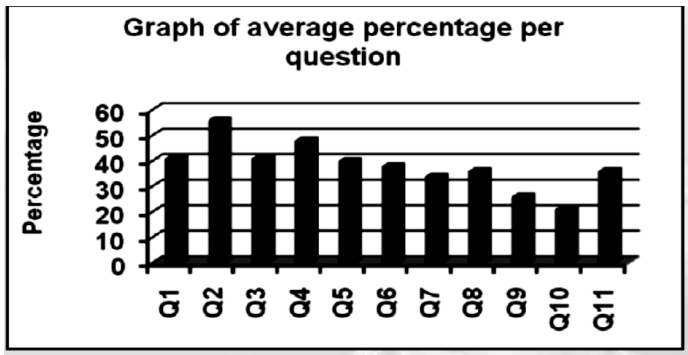
2.6 Misconceptions and learning difficulties in electrochemistry

It is common in teaching that students come up with non-scientific concepts from their environment and previous teaching that a teacher does not expect or are unfamiliar to him/her; these were called misconceptions by various researchers (e.g. Nesher, 1987). The sources of misunderstandings in electrochemistry include difficulties in learners' inability to reconcile their prior concepts (Geddes & Woods,1997), use of terminology (e.g. to switch from biological cells to electrochemical cells which are both seen as examples of isolated systems), following rules employed in electrochemistry (e.g. Sanger & Greenbowe, 1997) as well as wrong impressions given by pictures and improper classroom instructions and statements in textbooks (Ogude & Bradley, 1994; Schmidt, Mahon, & Harrison, 2007). Several studies of misconceptions in electrochemistry in high schools and the learning difficulties experienced by students (learners) in learning electrochemistry exist (see Garnett & Treagust, 1992a, 1992b; Ogude & Bradley, 1996; Sanger & Greenbowe, 1997; Yılmaz, Erdem, & Morgil, 2002; Hamza & Wickman, 2007). These researchers discussed problems students encounter in electrochemistry as well as pedagogical strategies that aid in addressing the identified problems. The authors found that students in different countries hold similar misconceptions that are specific to the topic and concept although these misconceptions vary from context to context. These misconceptions stand on the way of students' learning and thereby interfere with mastery of correct scientific concepts.

Garnett and Treagust (1992a) administered questions on concentration introductory college students after electrochemistry instruction to determine misconceptions. The misconceptions include: the notion that water is not

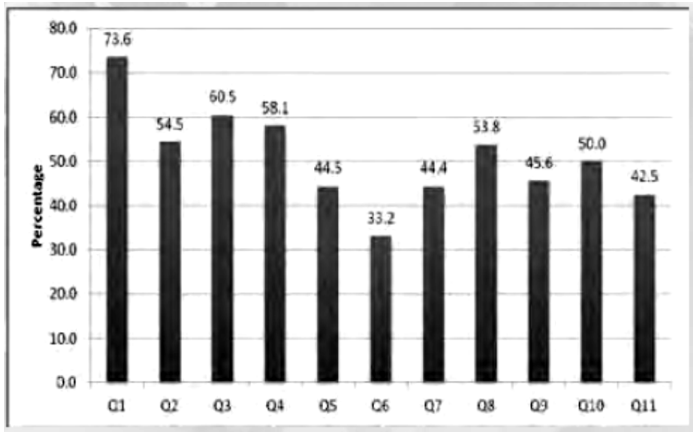
reactive in the electrolysis of aqueous solutions, students believed that electrons flow through the electrolyte and salt bridge to complete a circuit and the negative sign which are assigned to electrodes represent net electron charges. Students also had the notion that cell potentials are absolute and can be used to predict if the half-cell reactions are spontaneous or not and the cell potential are independent of ion concentrations (Özmen, 2004). Although learners had difficulties in mastering the concepts cell potentials, they were able to calculate cell potentials correctly. The results confirmed the research that students lacking an understanding of the electrochemical concepts were still able to solve quantitative examination questions. These results were confirmed by Schmidt *et al.* (2007, p.258) who argued that learners' alternative conceptions arise from the teaching method in which the learners first experience and learn about electrochemistry concepts and lack of understanding of the concept terms used.

The DBE (2011, 2012) reports the common mistakes and misconceptions by South African learners in the chemistry examinations and these are discussed below. Every year the Department of Basic Education presents a National Diagnostic Report on Learner Performance on electrochemistry questions in the NSC examinations. The report has consistently indicated an outcry in poor performance in electrochemistry related questions. The following figures attest to this outcry.



Q1	One-word answer to a statement – all content
Q2	MCQs – all content
Q3	Organic Chemistry – nomenclature
Q4	Organic Chemistry – physical properties
Q5	Organic Chemistry – reactions
Q6	Rate of reaction
Q7	Chemical equilibrium
Q8	Galvanic cells
Q9	Electrolytic cells
Q10	Chlor-alkali industry
Q11	Fertilisers
Q12	Photoelectric effect

Figure 2.3: Average performance of learners per question in 2011 chemistry paper (adapted from DBE, 2011)



Q1	One word items
Q2	Multiple Choice
Q3	Nonmenclature of organic compounds
Q4	Physical properties of organic compounds
Q5	Reactions of organic compounds
Q6	Rate of reaction
Q7	Chemical equilibrium
Q8	Galvanic cells
Q9	Electrolyctic cells
Q10	Batteries
Q11	Fertilisers

Figure 2.4: Learners average performance per question in 2012 chemistry paper (adapted from DBE, 2012)

Figure 2.3 and 2.4 show that the learner achievements in questions related to electrochemistry remain low as compared to other topics. The performance in 2012 however shows a slight improvement over 2011. Kriek and Grayson (2006) have blamed this low achievement on inadequate content knowledge of teachers in the topic. Taylor and Vinjevold (1999) added that in South Africa, "*Teachers' poor grasp of the knowledge structure*

of mathematics, science and geography acts as a major inhibition to teaching and learning these subjects" (p.139). As a result of these sentiments, Kriek and Grayson (2006), suggests that professional development programmes should aim at strengthening science teachers' content. Therefore, this study used the content knowledge test to uncover the physical science teachers' content knowledge on electrochemistry and this is discussed later in this chapter.

In addition to the evidence above about poor performance in electrochemistry questions, the DBE (2011, 2012) reported the following misconceptions in South African learners were reported on:

The function of salt bridge

- Learners think that ions move through the salt bridge from the one half-cell to the other half-cell.
- Ions move from the salt bridge into the half-cells to ensure that no built-up of charge takes place at the electrodes.

Common incorrect answers were the salt bridge:

- Maintains neutrality of the cell (should be *electrical neutrality*);
- Completes the cell /current (instead of *completes the circuit*);
- Connects the half-cells
- Transfer Cu^{2+} ions to Pb^{2+} ions and Pb^{2+} ions to Cu^{2+} ions
- It allows ions to move from the anode to the cathode or from the cathode to the anode
- Transfers electrons
- Separates the two electrolytes and
- Transports charge.

This is in line with observation made by Huddle, White and Rogers (2000) who found that a few students in their study had a coherent concept of the purpose of the salt-bridge.

On Redox reactions, the learners *think that electrons are lost* and thus *reduction* takes place (it seems as if learners think that reduction implies to get smaller and therefore electrons are lost). Hamza and Wickman, (2007)

made a similar observation. In the electrochemical cell part, when students where asked if they know what happens at anode and cathode electrodes, Hamza and Wickman found that learners had misconception in the electrode processes as depicted by one learner's response who said that the anode should be positive because it loses electrons.

The learners seem to think that the cathode is always on the right and the anode on the left (DBE, 2011). Linked to this misconception, many learners interpret a negative electrode to imply that the electrode is negatively charged. The report also indicated that learners struggle with questions that require the use of the Table of Standard Reduction Potentials. In addition many learners still retained the double arrows in the half-reaction (DBE, 2011). Sanger and Greenbowe (1997a) in their study found that many learners think that the first half cell is always anode and the other is the cathode. Garnett and Treagust (1992a) concluded that students holding "misconceptions about the way electricity is conducted in metallic conductors and electrolytes are highly unlikely to understand the operation of electrochemical cells" (p. 140). In a subsequent study, Garnett and Treagust (1992b, p.1097) found that students holding the misconceptions that "an electric current only involves drifting electrons" and that "the anode and cathode are charged" were unable to explain the movement of charge in electrochemical cells correctly. From the report, I align with researchers who concluded that learner worldwide hold similar misconceptions.

Different researchers proposed different strategies of remedying or overcoming these misconceptions and learning difficulties in learners. These studies provided either a conceptual change method or a technique to assist in eradicating these. Computer animations/ simulations (Yang, Andre & Greenbowe, 2003, 2004; Doymus, Karacop, & Simsek, 2010), computer assisted–learning (Talib, Matthews, & Secombe, 2005; Hartley, Treagust, & Ogunniyi, 2008) and models (Huddle *et al.*, 2000; Sanger & Greenbowe, 2000) are teaching strategies that can enhance conceptual understanding thereby implying that teachers should plan their instruction accordingly. Other strategies suggested include use of co-operative learning (Acar &

Tarhan, 2007), use of conceptual change text and jigsaw puzzle technique as well (Yürük, 2007). Building on this idea of promoting conceptual change, Karsli and Ayas (2011) combined different conceptual change techniques such as computer animations, conceptual change text, worksheet and hands-on activities and build a 5e learning model. In this model, the 5 Es represent: engagement, exploration, explanation, elaboration, and evaluation. This implies that each "E" represented part of the process of assisting students' learning sequence and experiences in linking prior knowledge with new concepts. This laboratory activity was aimed at eliminating prospective science teachers' misconceptions of electrochemical cells as well as improving their science process skill (SPS). Despite the efforts to remedy learning difficulties in electrochemistry, leaners still exhibit a gross number of misconceptions hence a need to diagnose teachers' topic specific teaching strategies.

Having identified the common mistakes made by South African learners in electrochemistry, an instrument was necessary to identify the physical science teachers grey areas in the teaching electrochemistry. Research has shown that the errors committed by learners are inheritances of their teachers. A diagnostic multiple choice test on content knowledge of physical science teachers was also needed to uncover their misconceptions on the topic as most studies concentrated on learners or students' misconceptions. Thus, this study adapted and modified multiple choice questions from literature and grade 12 past exam papers. These were used to measure content knowledge of teachers and uncover their misunderstandings or misconceptions. By knowing the teachers' content knowledge in the topic on electrochemistry, insights would be gained on whether it is lack of or poor subject matter knowledge or their teaching skills that contribute to low achievement of learners in public examinations as alluded to in the previous section. The teachers may develop better teaching strategies or learn from experienced teachers if they find that their current methods are not sufficient in addressing learners' difficulties in electrochemistry.

2.7 Summary

Literature related to attempts made to measure the quality of topic specific PCK of physical science teachers both practicing and pre-service has been reviewed. I started by looking at how Shulman (1986) defined the PCK construct and how other scholars viewed it and tried to measure and portray it. The Tailored model (Rollnick *et al.*, 2008) was found to be suitable for this study because it is a model of generic PCK into which a Topic Specific PCK model is built on. The model focuses only on the content knowledge domain. The TSPCK theoretical framework that guided the study was discussed in detail.

Research has established that a special relationship exists between content knowledge and PCK. Quite a number of researchers acknowledged content knowledge as the prerequisite in the development of PCK. In addition other studies demonstrated that teaching experience as well as teachers' beliefs was also determinants. Literature has shown that PCK within topics it is also domain specific. Aydin (2012) confirmed notion in his study in Turkey with two experienced chemistry teachers.

The chapter also gave an overview of studies to capture and measure generic PCK and topic specific PCK. Available instruments were also discussed. It is important to note that most instruments used to measure the topic specific PCK suffered methodological flaws like insufficient parameters for both teachers' PCK and TSPCK. For instance, the instruments used measured two or three teacher knowledge domains yet various researchers in mathematics and science education have identified curricular saliency (knowledge of curriculum), knowledge of what is difficult to teach, knowledge of representations including analogies, and knowledge of conceptual teaching strategies and students' prior knowledge as five components that enable transformation of CK. These aspects are useful to the teachability of the content so that it is understandable to learners. I then reviewed literature related to misconceptions on electrochemistry in general and then zoomed to misconceptions which are still prevalent to South African grade 12 learners-a grade where electrochemistry is examined.

Literature on strategies to overcome these learning difficulties was reviewed. Despite these suggestions misconceptions were still common and hence I saw to develop an instrument to diagnose teachers qualities of topic specific PCK in electrochemistry. In South Africa no such instrument has been developed and this is the major dimension of my study. The developed instrument would provide diagnostic information on the quality of topic specific PCK of physical science teachers as there is a belief that teachers with that a high level of PCK can make a considerable impact on the quality of teaching delivered by the teachers to learners and consequently on the quality of learning experience in most classroom environments (Grossman, 1990; Park *et al.,* 2011).

2.7 Projection to the next chapter

The next chapter discusses the methodology followed used to design the instrument, the participants, and the research instruments used to collect data, issues of ensuring reliability and validity of the developed instrument as well.

Chapter 3

Research Methodology

This chapter mainly discusses the research design and methodology used in the design of the instrument to measure the teachers' TSPCK on electrochemistry. First, I provide the methodology used in the study and the rationale. I then discuss the data collecting instruments used in this study followed by a detailed account of the steps involved in the design of the TSPCK instrument. Procedures for the adaptation of the instrument to measure the teachers' content knowledge are also presented as well as data analysis techniques. The research methodology is grounded in the research questions in section 1.3.4. Finally, ethical issues taken into consideration in this study, issues of validity and reliability and limitations of the study are also deliberated.

3.1 Introduction

The objectives of the study were first to design the instrument that could be used to measure the teachers' TSPCK of physical science teachers in South African context on a large scale; secondly, to find out how valid the designed instrument is and thirdly, to explore the relationship between the teachers' TSPCK and their content knowledge. In my discussions, I first provide the methodology used in the study and the rationale. I then discuss the data collecting instruments, their use and how they were developed. Therefore, most of the chapter is devoted to explaining the various stages of the development of the TSPCK instrument including its reliability and validity, as this is the main focus of the study. This was necessitated by the fact that on taking a scan of available instruments in literature none was able to provide all the desired criteria to measure the quality of teachers' topic specific PCK on electrochemistry (see section 2.4 on available instruments and their parameters).

The remainder of the chapter explains the adaptation, development and testing of the content knowledge tool, a tool which was used to measure the content knowledge of the physical science teachers. The measured content knowledge was intended to answer research question 3. In the last sections the issues of validity and reliability of the instrument(s) and ethical issues are discussed. Since *validity* is the main purpose of the study, substantive issues are dealt with in detail in the data chapters (see section 5.2-5.4)

3.2 Methodology and Approach

The study was conducted using Mixed Methods (MM) to address the research problems of the study and give answers to the research questions. The philosophical orientation associated with MM is pragmatist, employing both narrative (qualitative) and numeric (quantitative) approaches to answering research questions (Teddlie & Tashakkori, 2009). This research can be described as methodological in the sense that emphasis was on the process followed and subsequently the validity of the TSPCK tool on electrochemistry. MM were used because the design of the instrument requires both qualitative and quantitative methods in the various steps towards its creation. MM as a methodology, "involves collecting, analysing, and mixing qualitative and quantitative approaches at many phases in the research process, from the initial philosophical assumptions to the drawing of conclusions". On the other hand, as a method, "it focuses on collecting, analysing, and mixing quantitative and qualitative data in a single study or series of studies" (Creswell, 2006, p.18). This study was a single study where a TSPCK instrument was designed, validated for measuring TSPCK of physical science teachers.

Literature indicates that mixed methods provide accurate and increased levels of confidence in research findings (Kellie, 2001) as well producing new knowledge by combination of findings from different research approaches (Foss & Ellefsen, 2002). Other benefits identified include hearing different voices (Moran & Butler, 2001) as participants deliberate on the issues of electrochemistry under discussion and the complexity a phenomenon (in this case of PCK) is revealed in the process (Boaler, 1997).

In addition when methods are combined, the weaknesses of one method can be enhanced by the strength of the other (Johnson & Onwuegbuzie, 2004). The weaknesses of mixed methods include mixing of paradigms, analysing and interpreting conflicting results and above all they are time consuming. In my discussion I will highlight exact places where the different methods were used as stand-alone, as well as the cases where they combined or one converted into the other.

In this study both qualitative data and quantitative data were collected. Descriptive statistics was used to analyse qualitative data and at the same time this qualitative data was converted to quantitative scores. This was difficult in terms of interpretation as to when to use descriptive statistics or quantitative statistics. Despite these disadvantages the mixed methods approach still remains useful for the purpose of the study. I had 3 different research questions which I addressed through MM. I was able collect both qualitative and quantitative data. Since qualitative methods deal with only description of the participants in words the quantitative methods enabled me to categorise or rank these teachers into those with 'limited' TSPCK to those with 'Exemplary' TSPCK, that is, according to the quality of TSPCK they displayed. These categories will be described fully in chapter 5.

The qualitative research method answered the first and second research questions the 'how' part of the question which could not be answered by using only quantitative research. A description of the whole process of developing the tool gave rise to qualitative data. Validity and reliability of the developed instrument was achieved through quantitative method-statistics. On the other hand, the quantitative research provided answers to the third research question by answering the 'what' part of the problem which could not be done by the qualitative research only. From this discussion I can clearly point out that the weaknesses of one method was compensated by the other and thus an instrument which was both qualitative and quantitative in nature was developed to measure the teachers' quality of TSPCK on electrochemistry.

To be precise, qualitative methods were used during the initial stages of development of the tool where open-ended questions were designed and also during the pilot stages where the authentic responses were gathered using open ended question (see sections 4.2.2.6-4.2.3.1). In validating the semi-closed version, I utilised quantitative methods. Finally, in validating the final instrument (see section 5.3) I used both qualitative (the teachers reasoned out to justify their choices) and quantitative methods (responses were rated using a PCK rubric with a scale of 1-4). Here, qualitative method was converted into quantitative method. The teachers' scores from the TSPCK rubric were then converted into numerical values which were then analysed by the Rasch statistical package (details in section 5.3). In determining the reliability of the instrument using the Rasch model, quantitative research method was used. Furthermore, to determine if there was a relationship between the measured quality (as measured by the designed instrument) and the content knowledge using regression analysis and Pearson moment-product correlation analysis quantitative methods were utilised. Mixed methods are rigorous and the researchers argue that rigour can only be ensured when research designs with random assignment and selection are used selectively.

If the designed instrument is authentic and reliable it can add to literature and can be used to confirm results in case unreliability is suspected. The instrument is qualitative in nature as I used the teacher's verbatim to construct the multiple choice options. The amount of topic specific PCK possessed by teachers was then quantified by the Rasch statistical package so this is qualitative. In this case qualitative data was converted to quantitative. The following section presents the description of the all data collecting tools used in this study. The amount of PCK possessed by teachers was then quantified by the Rasch statistical package so this is qualitative. MM also enabled me to better understand of the topic specific nature of PCK as well as the relationship of Topic Specific PCK with the CK of physical science teachers in this study.The following section presents the description of the all data collecting tools used in this study.

3.3 Participants

The target population used in the validation and testing of developed instrument is the grade 12 physical science teachers in Johannesburg secondary schools, Gauteng province in South Africa and potentially any high school teachers teaching the topic of electrochemistry. I should make it explicit that the sample population is not a sample per se but it is used for the validation of the instrument as the study is about designing an instrument. A convenience sample of 21 grade 12 physical science teachers took part in the study. There were approximately equal numbers of females and males. A convenience sample was used because the majority of teachers were reluctant to take a content knowledge/subject matter diagnostic test and so they were chosen due to their willingness to participate and proximity. Some of the teachers were those whom I knew from neighbouring schools and from other subject information sharing meetings. I also utilised the practicing physical science teachers who were doing an honours degree part-time studies in science education at the University of the Witwatersrand due to their proximity. Therefore, participation was on voluntary basis. The criteria for the selection of practicing teachers was teaching experience varying from 5-20 years which included electrochemistry in the Further Education and Training (FET) phase (grade 12) and who were willing to take the test. Grade 12 is the exit grade in the South African schooling system and the grade in which electrochemistry is largely taught and examined. Teacher demographic information was also collected. This included the teachers' qualification, the length of their courses, their main subjects they majored in, the current subjects they are teaching, teaching experience and number of years teaching electrochemistry in FET (grade10-12) where this topic is taught. Demographic information is attached in Appendix A10.

3.4 Instruments

Recalling from chapter two it was noted that there are various methods of capturing and portraying PCK**.** Since teachers' topic specific PCK and content knowledge are the main focus of this study, diagnostic tests were designed. Stein, Barman, & Larrabee (2007) point out that diagnostic test may assist in uncovering any misconceptions or preconceptions that exist in various topics in science. I should make it explicit that TSPCK is more than the misconceptions but also about the transformation of content–the teachability of topic. In my study, two tests were designed or adapted –an existing one to uncover content knowledge and another one which was designed by the researcher to measure TSPCK.

The first test was adapted to uncover the content knowledge in electrochemistry, as well as some teachers' misunderstandings of the topic itself that could perpetuate misconceptions or errors in learners. There is a claim that some misconceptions arise from teachers holding misconception themselves and improper classroom instruction and statements in text books (Ogude & Bradley, 1994; Stein, *et al.*, 2007). This implies that misconceptions held by learners might have been taught to them by their teachers; therefore, there is a need to diagnose any misconceptions held by physical science teachers in South Africa through a diagnostic test. Hence in this study, teacher CK was measured using teacher *Content Knowledge achievement test* that was adapted from literature and grade 12 chemistry papers. Modifications made in the test are discussed later in section 4.4.1.

As discussed in chapter two, the teachers' PCK is difficult to measure as it is elusive (Kind, 2009). For this reason, the teachers' TSPCK was measured using the designed and validated *TSPCK* instrument-the second test. The TSPCK instrument aimed at collecting data on how the teacher reason using the five categories of TSPCK outlined in the previous chapter (section 2.4) as they teach electrochemistry whereas the content instrument gathered the amount of content knowledge possessed by these teachers. A PCK rubric employing a rating scheme was adapted and modified as well and used to score the TSPCK instrument to determine the quality of TSPCK possessed by

the practicing teachers. Modifications are shown in Appendix A11. The section that follows presents the description of the two data collecting instruments utilized, namely, the topic specific PCK (developed in this study) and a *Content knowledge achievement test* (adapted from literature).

3.4.1 Topic Specific Pedagogical Content Knowledge (TSPCK) instrument

Topic Specific Pedagogical Content Knowledge (TSPCK) instrument was developed in the study and used to collect data. This diagnostic instrument is a set of teacher tasks developed to measure teachers' topic specific PCK in the topic of electrochemistry. The instrument was developed to measure the teachers' TSPCK on electrochemistry in grade 12, as specified in the South African National Curriculum Statement (NCS) for physical sciences see attached Appendix A17). It tested teachers' knowledge on how they handle the topic on five categories outlined in section 2.3. The test consists of 6 sections namely:

- Demographic information,
- Category A: Learners' prior Knowledge,
- Category B: Curricular Saliency,
- Category C: What makes the topic easy or difficult,
- Category D: Representations/analogies/Models,
- Category E: Teaching Strategies.

The first section was to gather information about teacher demographic information such as gender and teaching experience etc. The other sections divided into five categories (Mavhunga & Rollnick, 2013) comprised of 10 test items. The first two test items in the TSPCK instrument are multiple choice items constructed from teaching scenarios asking for teacher responses to particular correct and incorrect learner statements. Since the TSCPK sought to identify the teachers' Topic specific PCK through their reasons, therefore, the second part of each test item gave a blank space in which the physical science teachers were asked to justify their choices or write an explanation of their reasoning. While some questions were prepared

by the researcher others were taken from literature (e.g. Pitjeng & Rollnick, 2012. The questions were vetted by a science reference team for relevance and appropriateness. This was done to ensure face and content validity. The composition and functions of the science reference team are discussed in detail in section 3.5. The development of the TSPCK instrument was answering the first research question:

- How can a valid instrument be designed for measuring the quality of teachers' PCK in electrochemistry?

The TSPCK instrument design process started with: (i) Conceptualization of test items, followed by (ii) construction of the instrument and judgment of items, then (iii) piloting and construction of the actual instrument and finally validation of the instrument**.** A detailed account on the entire design process is discussed later in section 4.2.1.1. Internal consistency of test items was measured using Cronbach's KR-20 alpha and it was found to be 0.84. At its various stages of development, the TSPCK instrument was initially subjected to a pilot test on a small scale to get comments from teachers which were used in refining the instrument, adjustments made as informed by pilot results and then implemented at a larger scale to determine the ease of its applicability, its reliability and validity. The final TSPCK instrument is included in Appendix A3.

3.4.2 PCK rubric

Separately but in conjunction with development of a TSPCK instrument, a PCK rubric was developed. Although, it was not part of the instrument, it was done to increase validity and reliability of the designed instrument. A PCK rubric was used to mark the teachers' responses and as a rating instrument. According to Park et al. (2008) the PCK rubric is an artifact used to measure the teacher's level of PCK based on teacher's observations while teaching and during pre and post teaching observation interviews. The rubric was used by researchers like Rowan et al. (2001) and Mavhunga & Rollnick (2011) where it proved that it can reliably measure specific qualities of PCK to evaluate the whole construct. However, in this study, the PCK

rubric (adapted from Mavhunga & Rollnick, 2011) was modified to assess the teachers' knowledge on the five categories of TSPCK through teacher tasks not through teacher observations in teaching and during pre and post teaching interviews as it was used by the authors (Park *et al.*, 2008). The details on how the PCK rubric was modified are discussed in detail in section 5.2. Also see Appendix A11 for detailed modifications and a complete rubric is in Appendix A12.

The rubric has indicators in each criterion that that must be met and a rating scheme as well. The PCK rubric acted as a guide in the awarding of ratings as well as classifying the teacher as having Limited, Basic, Developing and Exemplary TSPCK. The indicators listed in each criterion were supposed to be present in order to justify an award of a specific rating to a teacher. This made the whole process to be as objective as possible and also to increase the reliability of the ratings as much as possible and hence the final results in the event the rubric is used by independent raters to score the designed TSPCK instrument. As a scoring sheet, the rating of each teacher's response to test items was indicated by a mark in the relevant column of each row. Every row represented a criterion that showed progression of TPCK from 'basic' to 'exemplary'. The rubric had 5 columns and 5 rows. The first column contains the five categories of TSPCK whilst columns 2 to 5 contain the ratings f

or that criterion. Each category of TSPCK is graded using a four-point scale ranging from 1-"Limited" to 4-"Exemplary" for a possible total points of 20 for the whole instrument

The scores were then analysed by Rasch statistical model package (see section 5.5-5.5.2). This was an attempt to answer the research question:

- How valid is this instrument in measuring the Topic Specific PCK of a sample of experienced teachers in electrochemistry in the Gauteng Province?

3.4.2 The Content Knowledge Tool (CK)

This is a diagnostic test instrument consisting of 21 multiple choice items in which two of the questions required participants to explain a reason type test item. The test required the participants to choose a "correct" response from the five possible responses given. As mentioned earlier in this section the CK test was used to measure the teacher' subject matter knowledge on the topic on electrochemistry. In two of the 21 questions-question 3 and question 10 respondents were to choose the best option among the given options as well as explain their choices. It is based on various questions on electrochemistry concepts adapted from literature which are usually prone to misconceptions and also provide difficulty to learners in the South African examinations as reported by the DBE (2012) report on learner performance on this topic electrochemistry. It is largely, derived from the test that was designed by Ogude (1991) in her thesis and Ogude and Bradley (1994) on students to measure their understanding of the electrochemical cells, conduction in the electrolyte and electrode processes. The similar set of questions was employed because it was assumed that learners hold similar misconception as their teachers (Ogude & Bradley, 1994; Schmidt *et al.*, 2007). The process of adaptation and modifying the content knowledge tool are going to be discussed fully in the section 4.4. The Content Knowledge instrument is in Appendix A3. Data collected was used to answer the research question:

- What is the relationship between the measured quality of their Topic Specific PCK of teachers and their content knowledge in electrochemistry?

A memorandum was used to score the CK test (see Appendix A5). A final TSPCK and CK instruments were then administered on a large scale to 21 practicing physical science teachers. As aforementioned, a memorandum was used to mark the responses of teachers in CK achievement test while a PCK rubric marked responses on TSPCK achievement test. The participants took approximately 80 minutes to complete the TSPCK test and 30 minutes to complete the CK test.

3.5 Validation of the instrument by the experts

Validity and reliability are of paramount importance in designing of instruments and these are used to determine the quality of instruments. This study utilised content and construct validity, as well as face validity. Reliability of the test and persons taking the test was also achieved through Rasch model (see section 3.6 for details). Triangulation of opinions ensured validity of content during the construction process and reliability on marking the responses collected using the instruments. To achieve face validity, the opinion of reference team was sought to assess and vet the questions throughout the designing, testing of TSPCK, as well in adaptation and modification of questions CK instrument and the PCK rubric. A science reference team consisting of science education chemistry lecturers, two practising physical science teachers with many years of teaching the topic at grade 12, and the researcher examined the instrument for face and content validity. In content validity the chemistry experts ensured that the items were properly constructed and were not heavily testing content in the TSPCK instrument (as there was a content knowledge test to be administered in parallel to the TSPCK).

The experts checked that each item in the instrument is related to what it is supposed to measure. They also checked whether questions were relevant, precise, worded properly and are appropriate in length, if there was any ambiguity in questions so that test items would be interpreted correctly by respondents (Creswell, 2012). They also checked if each question in the instrument was in alignment with the five knowledge components of the TSPCK and complexity of electrochemistry content in NCS (DBE, 2011). The extract from NCS document is attached in Appendix A17. To assure validity, the independent peer validators scored the tests independently to check if the scores I awarded were consistent with theirs and also the explanations given by the respondent were scientifically correct. Over 80% agreement was achieved with changes made after a compelling argument.

3.6 Data analysis

Analysis entailed establishment of validity and reliability first through the use of the Rasch model statistical programme. Secondly, validity was confirmed qualitatively by comparing the theoretical postulated order of the rank of difficulty of the five knowledge components to an empirically calculated order. Findings are recorded and discussed in form of a research report in chapter 5.

A Topic Specific PCK rubric was used to mark the completed teacher responses. The TSPCK rubric is attached on Appendix A12. The Rasch model provides two reliability estimates: one of the person taking the test and on the items contained in the test (instrument). Bond and Fox (2001) assert that in the Rasch statistical analysis model, raw data scores are converted to probability measures on an equal interval scale in order to calculate both person and item reliabilities, while validity is established through the 'Fit statistics'. The reliability and validity values are established from the raw scores generated from marking the completed responses. In marking the responses, both the answer as chosen from the multiple test options and the qualitative description provided on the rationale will be used in determining the qualitative category and therefore the numerical score on the Topic Specific PCK rubric. Two peer independent raters also marked the test using the rubric and scores were compared and an agreement of 85% was achieved. This step was done to ensure the validity of the designed TSPCK instrument. The Cronbach's KR-20 alpha value of 0.5 is the traditional score which measures the statistically fitness of the instrument and reliability. This value indicates moderate or relatively high reliability for a diagnostic test. The higher reliability indicates a good spread of scores by the persons in the sample. High item reliability indicates that the developed tool has both test items that easier and more difficult (Bond and Fox, 2001). The internal consistency of the tool should be between a statistical range of -2 and +2 and this is a traditional statistics measure if both the persons and items are measuring the same construct-in this case the topic specific PCK.

If the person and item difficulty are within this range it show that they are in good match, their coherence and that they are normally accepted.

The content knowledge instrument was scored on a continuous scale from 0 to 27 using a memorandum. It was also validated by independent validators as well. An agreement of over 80% was achieved on validation. A correlation between TSPCK and CK was calculated using measured by the Spearman's moment product correlation coefficient and a regression analysis was carried to establish how strong the relationship between the quality of measured PCK and CK is.

3.7 Ethical issues

One month before the study commenced, an information letter about the purpose of study was sent to all the teachers concerned (participants). The information sheet is attached on Appendix A7. At all stages, before administering the two developed TSPCK and CK instruments, individual participants were informed about the purpose of the study. This was a step to ensure honesty and transparency-measures which Griffith (1998) suggested would make sure the researcher follows ethical issues in carrying out research. I guaranteed the participants anonymity and that all information collected during study was confidential, that they would not be harmed or the study would not jeopardise their job or cause loss of their job due to their participation and that they could withdraw from the study if they wished. To ensure anonymity and confidentiality, the codes were used to identify each participant. They were asked to sign consent forms to show their willingness to participate (see Appendix A8). The participants were further informed that the data would be shared with others in conferences or workshops and also it would be stored in a secure place for 3-5 years and thereafter shredded. Ethics approval was obtained from the University of the Witwatersrand ethics human subjects committee before data collection commenced. A clearance certificate was issued to show my conformity with ethics requirements and is attached on Appendix A9.

3.8 Conclusion

This chapter described the mixed method research design, methods used in the collection and analysing of data and the participants. A description of the structure of the tests (TSPCK and CK), the PCK rubric and their uses were also described. A detailed account of the steps taken to ensure rigour, reliability and validity of the designed instrument(s):-the TSPCK (designed) and CK achievement test (existing but modified) is discussed. Ethical issues and limitation of the study were also highlighted. The designed instruments measured what they were supposed to measure during their testing process. The study shows that it is possible to design a topic specific PCK instrument that is reliable and valid in measuring the quality of PCK of physical science teachers and the results are consistent with those found in literature.

3.9 Projection to the next chapter

The next chapter gives a detailed report on the process of developing the TSPCK instrument.

Chapter 4

The Process of Development of the instrument(s)

This chapter unfolds the steps that were followed in the development of the TSPCK instrument and the adaptation of the content knowledge instrument. In the discussion below, I am outlining the steps involved in the design of the TSPCK instrument from its conceptualization through drafting of test items and piloting to a version for validation. Towards the end of the chapter I indicate the procedures for the adaptation and modification of the instrument to measure the teachers' content knowledge.

4.1 Introduction

This chapter focuses on the various stages of the development the TSPCK and CK tool instruments and testing to check its reliability and validity. Most of the chapter is devoted to explaining the different phases of designing the TSPCK instrument and its validation as this is the main focus of the study. This was necessitated by a need to establish the level of PCK in electrochemistry of local teachers, following poor performance of learners in the national examination in the topic. So on taking a scan of available instrument in literature none was able to provide all the criteria to measure the quality of teachers' topic specific PCK on electrochemistry (see Chapter 2, section 2.3.3). As a result I took recommendations by Creswell (2012) that if you cannot locate the instrument on literature, you have to design it.

In South Africa, literature indicates that the South African physical science teachers usually suffer from lack of content knowledge. As a result, in conjunction with measuring the topic specific PCK, the teachers' content knowledge was measured using the content knowledge achievement test. Consequently, the remainder of the chapter explains the adaptation, development and testing of the content knowledge tool, a tool which was used to measure the content knowledge of the physical science teachers. The measured content knowledge was intended to answer research question 3.

4.2. The development of TSPCK instrument in Electrochemistry

The method for the construction of test items was similar to that of used by Rohaan et al. (2009) who used the following steps in a chronologically order:

- Conceptualization of test items,
- Construction of the instrument and judgment of items,
- Piloting and construction of the actual instrument and finally,
- Validation of the instrument.

4.2.1.1 Process of designing the TSPCK tool

The process of instrument development and validation followed the steps summarized in figure 4.1 below.

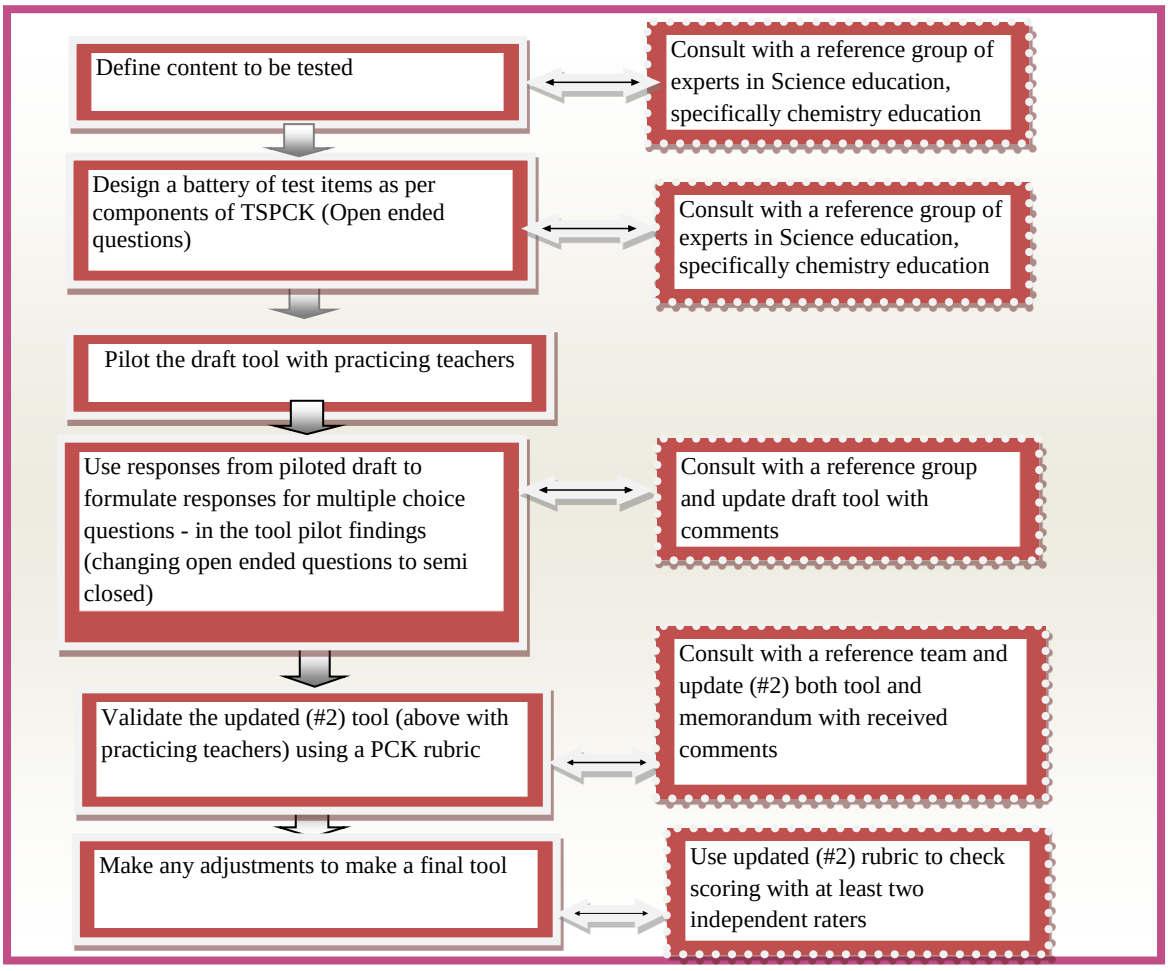


Figure 4.1: Summary stages in the development of TSPCK instrument

The section below describes each stage of instrument development outlined in the flow chart fully.

4.2.2.2 Step 1: Conceptualization of test items

In order to make reliable and valid inferences from the study based on teachers' accomplishment/attainment the study must use test items that are in alignment with electrochemistry content taught in grade 12 so as to infer about their knowledge of the content and PCK. This implies that the test items must match with the curriculum needs and standards (Ahn & Choi, 2004; La Marca, 2001) as well as the categories of TSPCK which enables this content knowledge to emerge. Opie (2004) argued that in order to achieve this one can use the content match and depth match. Content validity examines if the test content match up with subject area content, the objectives and assessment standards of the broad electrochemistry curriculum to be taught. On the other hand, depth match would check how well the test items match the complexity of knowledge and skills of the curriculum standards.

The design of the instrument followed similar steps used in literature by researcher such as Rohaan *et al.* (2009) who developed a PCK tool specific to measure the quality of PCK in Technology education. Care was taken to ensure that the test items were measuring PCK not content. Given that PCK is broad and tacit, it was a challenge to develop PCK test items, an experience confirmed by Kromrey and Renfrow (1991). For this study, a PCK test item seeks to elicit the reasoning on the teachability of a concept using either or combinations of the five components of TSPCK. The components as listed in Chapter 2 are (i) Learner Prior Knowledge; (ii) Curricular Saliency; (iii) What makes topic easy or difficult to understand; (iv) Representations; and (v) Conceptual Teaching Strategies. This means that a respondent should have sufficient content knowledge in order to think about the concepts in a topic in terms of the five components. In responding to PCK test items, a teacher's response was expected to demonstrate the grasp of content knowledge of the topic in question reasoned through the five categories of TSPCK in which transformation of content knowledge emerges (Mavhunga, 2012). Since there is no exclusive single correct response, acknowledging the many different ways of engaging, implied here, is that

the examinee should have sufficient content knowledge (Carlson, 1990) and PCK within the specific topic to recognize the appropriate application of a specific instructional principle or rationale through five knowledge components of topic specific PCK (Mavhunga, 2012). Thus there would be more than one correct response and no responses based on incorrect content knowledge.

Similarly, Kromrey and Renfrow (1991, p.5) defined their content-pedagogical items (c-p items) as the class of items for which the examinee's determination of the correct response depends upon knowledge of treatment of educational situations. Their definition excluded those items that focused on content exclusively without educational context as well as those items that addressed general pedagogical ideologies in the absence of content-specific associations. The authors suggest that the test items should assess more than the teachers' minimum basic knowledge of the topic. From the definitions above, the implications are that content knowledge is a prerequisite in answering the PCK test items. In separate but related studies, Rollnick et al. (2008) in chemistry and more recently in physics, Borowski, Kirschner, and Fischer (2011) confirmed this direct relationship between CK and PCK for experienced or practicing teachers. The choice of the content was facilitated by the common mistakes or misunderstandings which were prevalent in the grade 12 physical sciences paper 2 (chemistry) national examinations as entailed in the report by the DBE (2011, 2012). The misconceptions were similar to those in literature identified by most researchers such as Garnett and Treagust (1992), Ogude & Bradley (1994) and Nester *et al.* (2007) to name a few.

4.2.2.3 Defining the content to be covered

The whole process of the design of instrument began with identifying the main concepts in electrochemistry (as suggested by Treagust, 1988) and deciding on which ones to include in the tool. For example, the report (DBE, 2011) indicated that the majority of learners could not explain how electrical neutrality is maintained in voltaic cell due to misunderstanding of the

function of the salt bridge and therefore, the understanding electrical neutrality in galvanic cells by teachers was worth diagnosing.

Below is the content which is covered by the TSPCK instrument. The content was vetted by the science reference group for relevance and alignment with the South African national curriculum assessment standards of grade 12 electrochemistry. Initially I had selected content based on misconceptions and after vetting, the reference group wrote the following comment:

"*Content is not selected because of misconceptions but because of big ideas*" and hence big ideas were also identified.

4.2.2.4. Electrochemistry content covered by the instrument

The two instruments the TSPCK and Content knowledge tool covered the following content:-

1. Spontaneous and non-spontaneous reactions
2. Redox reactions
3. Electrochemical cells
4. Voltaic/galvanic cells using spontaneous reactions to generate electrical energy.
5. Electrolytic cell: using electrical energy to drive non-spontaneous reaction and this included the understanding of processes and redox reactions taking place in these cells.
6. Electrical neutrality
7. Half-cell reactions and electrode potential.

The selected content was translated into big ideas (Loughran *et al.*, 2004) instead of propositional statements as Treagust (1988) did in their instrument development process.

4.2.2.5 Big Ideas

Before designing test items to include in the instrument, the gate keeping concepts normally referred to as big ideas by Loughran *et al.* (2004) were determined.

Through discussion, the following big ideas were agreed upon between the researcher and the science reference group:

(i) Ions in solution carry charge.
(ii) Energy from chemical reactions produces electricity.
(iii) Electricity can be used to produce a chemical reaction.
(iv) Electrochemistry has important applications in everyday life.

4.2.2.6 Step 2: Construction and judgment of the test items

A topic specific PCK instrument was developed similarly to Mavhunga and Rollnick (2012). The instrument was constructed according to the five components of the TSPCK theoretical model in Chapter 2. Table 4.1shows the type of items that were designed for each of the components.

Table 4.1: Types of questions to be designed for the various components of TSPCK

Component	**Type of Question**
Learner prior knowledge	Teaching scenarios asking for teacher responses to particular correct and incorrect learner statements
Curricular saliency	Questions about sequencing of concepts in the curriculum, and identification of Big Ideas
What is difficult to learn	A direct question on why various sub concepts are difficult to learn
Representations	Teachers asked to respond to different representations commonly used in the teaching of the topic
Conceptual teaching strategies	Teachers respond to a scenario on teaching of a difficult section of the topic

In this study, I named the five components of TSPCK categories A-E in the instrument. Under each category I generated 2-3 sub-questions. The test contained a total of 11 questions which I generated and the questions were grouped under the 5 categories which made up test items. Therefore, the number of questions generated under each category is summarized in the Table 4.2.

Table 4.2: Number of questions designed for the various components of TSPCK

Category	**No of questions**
Category A: Learner prior knowledge	**3 questions** :- A scenario in which a learner had written in his/her script a misconception about how electrical neutrality is maintained in a galvanic cell/ scenario in class where a learner needed a confirmation of the fact that oxidation occurs in the anode in both electrolytic and voltaic cells.
Category B: Curricular Saliency	**2 questions and question 4 had 3 sub-questions** Questions on understanding of the 'big' ideas in electrochemistry, sequencing of these big ideas and the linkage with other subordinate concepts. The sub-questions required teachers to identify the topics that the learners need to be taught before electrochemical cells which are only taught in Grade 12 as per the NCS of South Africa.
Category C: What is difficult to learn	**1 question** on identifying with reasons which topics they consider to be difficult or easy to teach. This tested their awareness on the knowledge of the curriculum based on their experience in teaching the topic.
Category D: Representations	**1 question divided into 3 sub-questions:-** on identifying the representation/model and state with reasons the one which they dis/like. In the last sub- question the teachers were to make a choice on the given representations and explain how they are going to use it in class for learners grasp the concepts of electrochemical cells and the processes involved.
Category E: Conceptual teaching strategies	**3 questions**- based on wrong answers written by learners in which teachers were to identify errors and explain the strategies they will use to make learners understand the concept of oxidation and reduction.

For the pre-pilot of each component, open-ended questions related to electrochemistry were asked. This was the qualitative aspect of the research design. The open-ended questions were to stimulate discussion about the topic so that the physical science teachers would comment on the test items included in the instrument. The open-ended questions were also seeking sample answers. The open-ended questions enabled the participants in the

study to provide information about their experiences in teaching electrochemistry and their opinions. These were teacher tasks, not content based questions and created within the teaching context as indicated on Table 4.2.

The questions were teacher tasks, based on electrochemistry concepts covered by the South African physical sciences curriculum at grade 12 (see Appendix A17). This formed draft 1 of the TSPCK instrument which is shown in Appendix A1. The questions addressed the teacher on what s/he would do with the content, so understanding of the content is implicit. By so doing the qualitative methods enabled the researcher to understand the behaviour or nature of PCK they possessed in the topic. A battery of open-ended questions was developed to determine the most suitable test questions for each of the five knowledge categories of TSPCK.

According Creswell (2012) in evaluating content validity of instruments the researchers usually seek advice from the experts in the subject to ascertain if the questions are valid or not. This idea warranted the establishment of a science reference team. Consequently, in this study, a reference team comprised of professionals in science education chemistry consisting of the two project supervisors and myself. In addition, two to three experienced practicing teachers were added to the reference team. The reference team assisted in establishing content validity and aspects related to the accessibility of the language of the tool.

Although the test items were not actually addressing content *per se* they were based on correct subject matter, so design of test items required adequate content knowledge of electrochemistry. Extensive planning was spent in creating teacher based tasks. This was to ensure that any purely content related task was excluded from this test which was intended to consist only of PCK test items. This was in line with the observations made by Kromrey and Renfrow (1991) who also noted that PCK test items are not easy to construct. The authors argued that the construction of these items requires extensive planning, and special crafting as compared to

constructing subject matter knowledge related items. This was so because they felt that in order to write PCK test items it requires meta-cognitive knowledge of the teaching practice.

4.2.3.1 Creation of semi-closed questions

As described in the previous section, this section describes how the questions were formulated in the instrument. Some of the questions were scenario situations about learners' errors, misconceptions or situations where they needed confirmation about a certain concept they are not sure about in which teachers were to show how they handle such scenarios in a classroom environment. This followed a similar technique used in designing more recent quantitative instruments in literature that measured the same phenomenon (see instruments used by e.g. Riese & Reinhold, 2009 in mathematics), in science (e.g. by Park *et al.,* 2011; Tepner & Witner, 2011) and in technology education (Rohaan *et al.*, 2009). Also, question 1 and 2 included setting a classroom context in which a response was to be given (verbally or written) to a learner. Other scenarios included the following actions: explanation and giving feedback to learners (question 1 and 7); identification of big ideas and sequencing the concepts to show the order of teaching, then organizing topics or concepts into a mind map to show linkage with identified big ideas (question 4), giving opinions about different representations/analogies used in electrochemistry and demonstrate how they can incorporate a representation they liked most into their own teaching (question 6), and finally indicating teaching strategies for conceptual understanding that could be used to correct an erroneous understanding of concepts by learners (question 7).

The instrument consisted of seven questions classified according to 5 categories of topic specific PCK as outlined in section 2.4 above. The question on teaching strategies was adapted and modified from Pitjeng and Rollnick (2012). Examples of first draft open ended questions in Category A are given below.

CATEGORY A: LEARNERS' PRIOR KNOWLEDGE

1. What comment would you write on a learner's script who writes:

   "The purpose of the salt bridge in a galvanic cell is to conduct electrons"

Write your comments in the space provided below

2. State the difference spontaneous and non-spontaneous reactions?

3. How do you identify the element that has been oxidized in a chemical reaction?

Figure 4.2: Sample open-ended questions in TSPCK first draft Category: Learner Prior Knowledge

Figure 4.3 shows the example of a question in Curricular Saliency category.

CATEGORY B: CURRICULAR SALIENCY

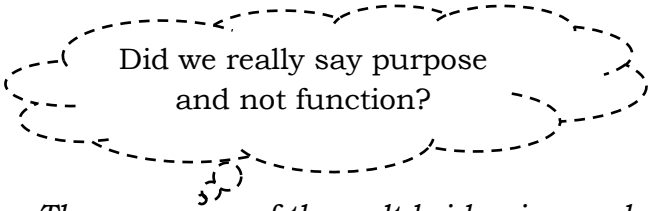
1. What topics must have been covered in chemistry before you can teach electrochemical cells?

List of Topics to be taught before electrochemical cells	**Sequence the topics** (the one to be taught first , place it as No. 1)	**Provide reasons for the proposed sequence**
	1.	
	2.	
	3.	
	4.	

Figure 4.3: Example of question in Category Curricular Saliency

The questions were vetted by the reference team first for suitability as PCK measuring questions, then also for the suitability of the teacher task and context proposed. The reference team suggested that these teacher tasks should be asked in certain classroom contexts be it verbally or written, spaces to write responses should be provided instead of ruler lines and content questions such as question 2 and 3 must be removed. In a language

check, the reference team felt that question one should be rephrased and the word "purpose" must be removed and replaced by "function of salt bridge…" as the it most appropriate word. See their comment below.



*The **purpose** of the salt bridge in a galvanic cell is to conduct electrons"*

The reference team comments were taken into consideration and after face validation; the question was refined and read as follows:

CATEGORY A: LEARNERS' PRIOR KNOWLEDGE

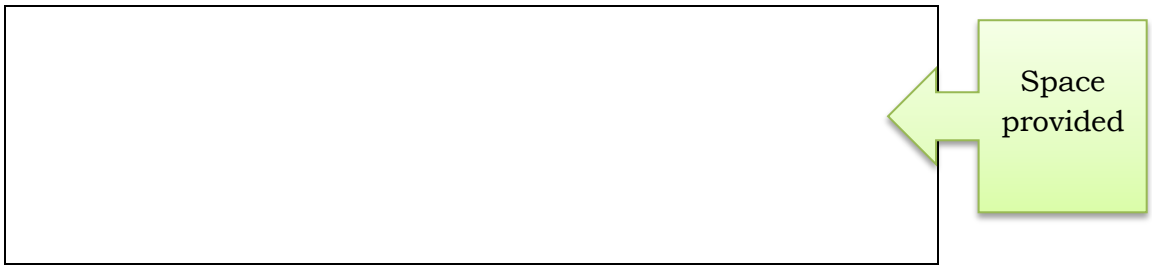
Context now indicated

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

Question rephrased

Write your response in the spaces below.



In this scenario, the context is written in bold and space was provided as shown above.

One question tested the teachers' knowledge about the awareness of the curriculum and the big ideas related to this topic of electrochemistry. These big ideas were mixed with subordinate ideas of the topic and the teachers were required to isolate these. The teachers were further asked to provide a

sequence of teaching these 'big' ideas with reasons for following such a sequence and link these ideas with subordinate concepts in a concept map (see question 4.1-4.2 in TSPCK instrument attached in Appendix A4).

Judgment of the reference team was sought to vet the draft instrument for ambiguity of questions and wording, The TSPCK instrument was updated following the comments from the reference team. This was the updated draft 2 version of instrument that went for piloting. The draft 2 instrument is included in Appendix A2.

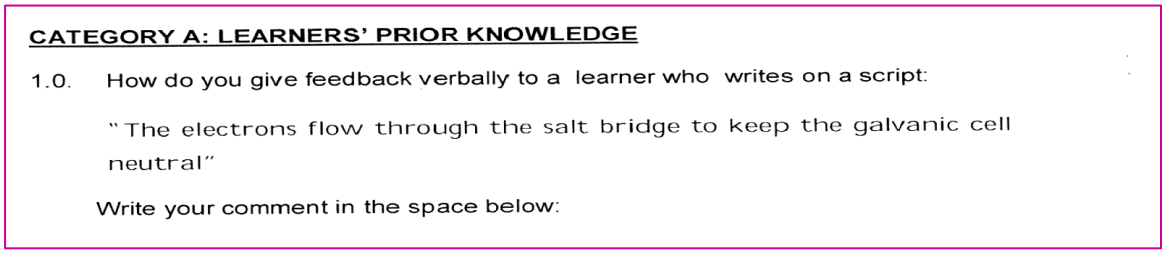
4.2.3.2 Step 3 Piloting instrument

Approved open ended test items were organized into a draft tool with clearly distinguishable headings of the five knowledge components. These were piloted with 3 experienced physical science teachers doing their masters in science education degree part time at the University of the Witwatersrand after they were informed about the purpose of the study (see Appendix A7) and seeking their consent (see Appendix A8). In the draft tool, the test items remained open ended in nature with in-built spaces for writing responses. This allowed for descriptive responses (qualitative data) to be collected from the participants about issues on the instrument and their authentic responses to test items were then used to develop the multiple options for tool as well as refine the questions. A cover page was designed to capture the demography and background of teachers who participated in piloting stage. The criteria for the selection of practicing teachers to pilot the tool is teaching experience varying from 5-20 years which should include electrochemistry in the FET phase (grade 12). Grade 12 is the level at which the study was located as most of the topic is covered at this grade. Participation was on voluntary basis. The physical science teachers were given as much time as possible to write their responses and the time taken to complete the test was by each respondent was approximately 90 minutes. Since the questions were open-ended in nature, the participants used much of their time to write their explanations as demanded by the questions. This was done to solicit their authentic ways of teaching the topic of

electrochemistry and their actual verbatim they use in explaining concepts to their learners in class. The extent of engagement with the question such as acknowledgement of the learners' misconception or pre-existing knowledge, thereafter providing a brief explanation to clarify the uncertainty or to confront the incorrect statement were some criteria used to choose responses that formed the multiple choice items that went into the final questionnaire (instrument). The difference in the choice of responses was the degree in which a response engages with the question. For example, the teacher's response that just repeated the correct content without further providing an a further explanation was earmarked for responses showing Limited TSPCK.

4.2.3.3 Analysis from pilot

The statements containing teachers' verbatim answers from the pre-pilot were analysed and selected responses used as multiple choice question options. This was the qualitative aspect of the methodology. Here are the examples of responses obtained from some of the teachers in the pilot phase. The figure 4.4 shows an extract from the question in Category A: Learner' Prior Knowledge.


CATEGORY A: LEARNERS' PRIOR KNOWLEDGE

1.0. How do you give feedback verbally to a learner who writes on a script:

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

Write your comment in the space below:

Figure 4.4: An extract of question in Learners' Prior Knowledge category

Here are the examples of responses obtained from some of the teachers in the pilot phase

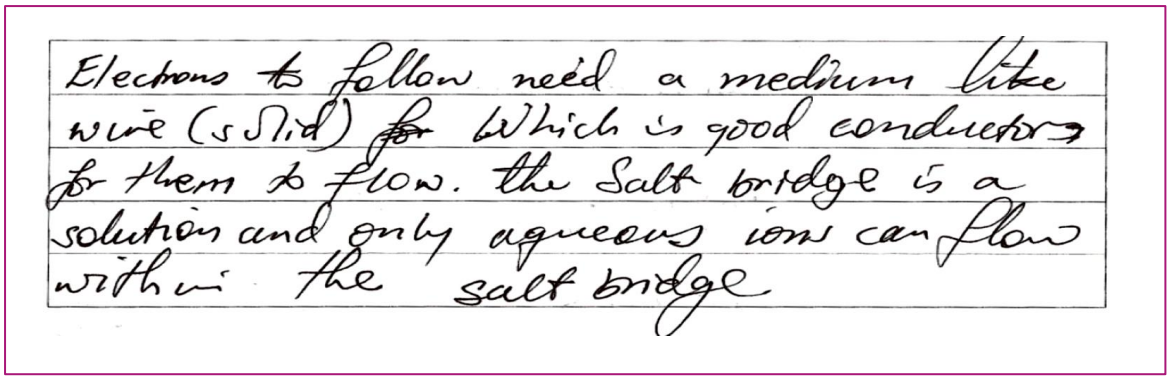


Figure 4.5: A response from *Sarah from pilot study

Sarah' s response is special in the sense that she engaged fully with the question as the teacher confronted the incorrect statement and further distinguished on what flows in the salt bridge and wire. However, Sarah did not explain to the learner what maintains electrical neutrality in galvanic cell. Despite, the aforementioned problem in the Sarah's answer, this makes this response to be earmarked for use in the final instrument as a distracter**.**

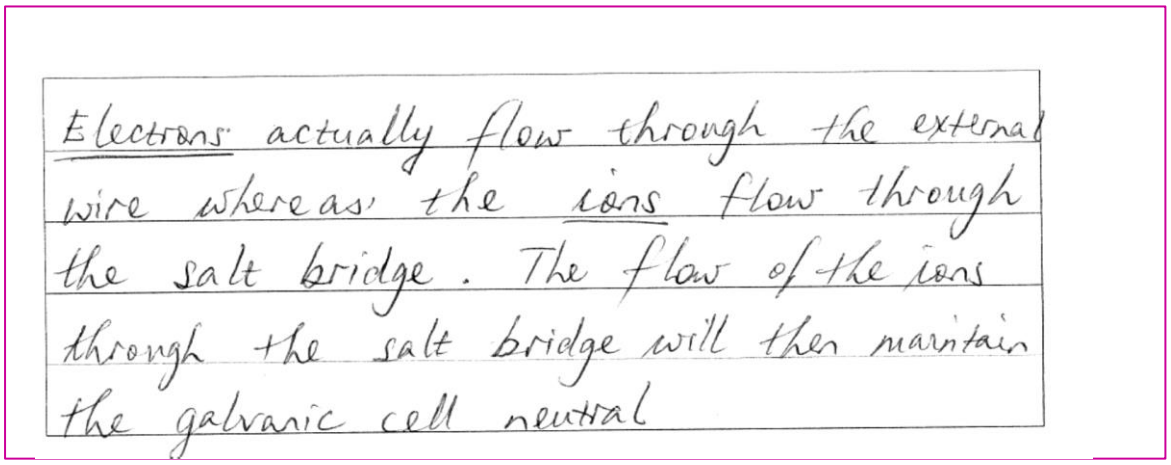


Figure 4.6: A response from Pupu* from pilot

Note: * these names are fictitious not real names of participants for ease of distinguishing.

Pupu's response also shows full engagement with the learners' uncertainty and like Sarah the teacher explained where ions flow as well as where electrons flow. The difference is that in addition to explaining on what moves where Pupu, went on to explain how electrical neutrality is maintained in

the galvanic cell which is lacking in Sarah's response, This makes this response more appropriate as a correct response in the final instrument as it shows correct content and detailed process of maintenance of electrical neutrality, a concept which the learner was not clear with. This response could form the basis for selection of a teacher who displays developing or exemplary PCK.

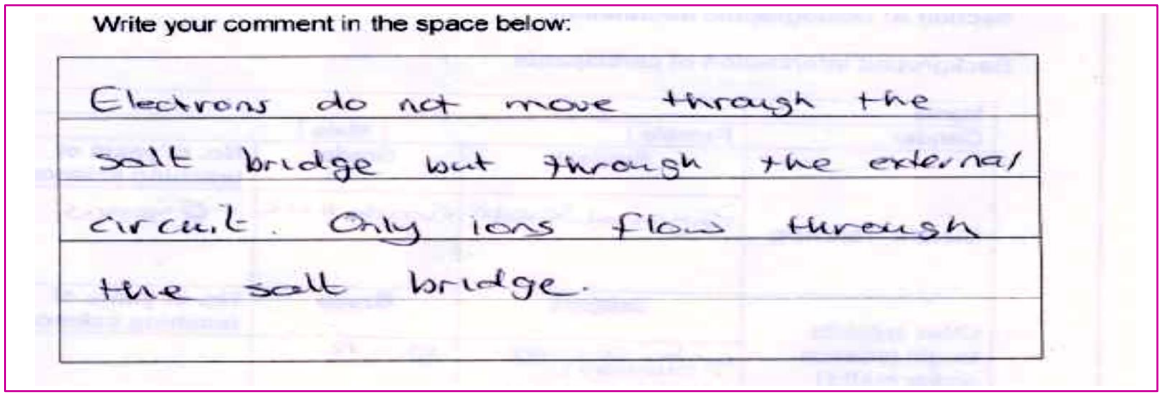
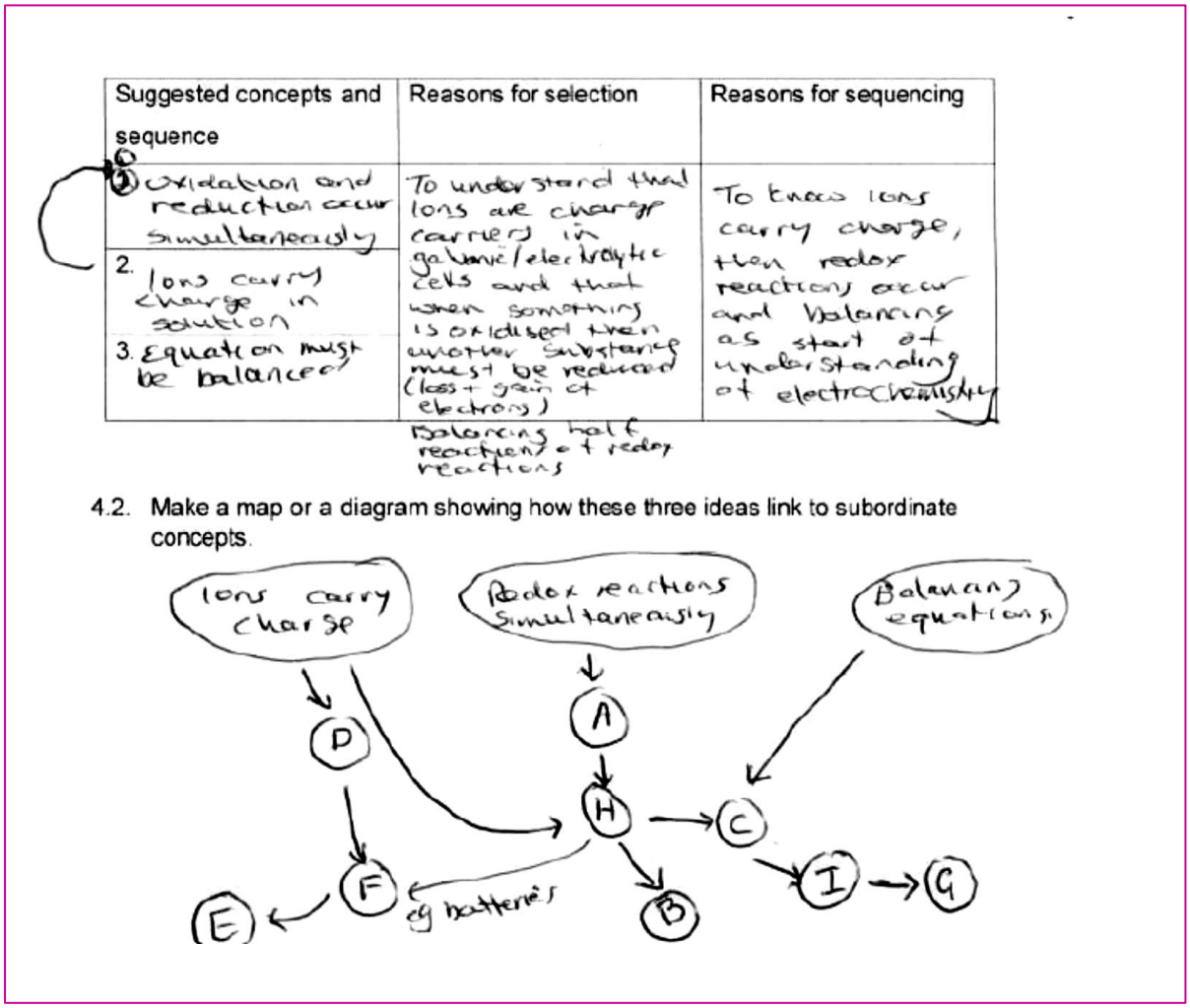


Figure 4.7: A response from Kabelo*

The response by Kabelo shows that the learner's response is incorrect by acknowledging that the electrons do not flow in the salt bridge but in the external circuit-the teacher acknowledged the learner's prior knowledge. He merely provides the correct knowledge without enlarging. This response may add further confusion to the learner as s/he might not know the external circuit and it is not clear how electrical neutrality is maintained. This response may be used to distinguish a teacher who has limited PCK from those who have exemplary PCK.

In the **Category B; what is difficult or easy to teach**, a variety of responses were obtained. What was interesting is that the participants in the pilot managed to choose the big ideas and provide a sequence of those gate keeping concepts with justification. In certain responses all the big ideas from the sequence while other participants provided a list of big ideas muddled with subordinate concepts. Fig. 4.8 shows an example of the response obtained from the pilot depicting the latter scenario.



Suggested concepts and sequence	Reasons for selection	Reasons for sequencing
1. Oxidation and reduction occur simultaneously	To understand that ions are charge carriers in galvanic/electrolytic cells and that when something is oxidised then another substance must be reduced (loss + gain of electrons)	To know ions carry charge, then redox reactions occur and balancing as start of understanding of electrochemistry
2. Ions carry charge in solution		
3. Equation must be balanced		

Balancing half reactions of redox reactions

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

Figure 4.8: Alex's response from pilot

Alex's response shows that he was aware of big ideas in electrochemistry but could not distinguish them from sub-concepts and hence was mixed up. The explanation for the reasons for selection the big ideas in the order given by the teacher was muddled. This was the same case with other physical science teachers in the pilot study. Despite the scenario given above on the question of big ideas, this question proved to be a good one to be retained as all the participants shown that they were aware of big ideas in electrochemistry. It was worth finding from a larger scale if this was a true reflection of what happens in most schools.

The authentic responses were used as distracters for questions 1 and 2 which were multiple choice items with a motivation space for choice of a particular response. The responses also gave the indication of the clarity or

ambiguity of test items. These facilitated the earmarking of test items that were good to be included in the final instrument and those that needed exclusion.

4.2.3.4 Step 4: Finalizing the instrument

Based on the observations from the pilot e.g. the time taken to complete the test was long (over 90 minutes), there was a need to shorten the test. As a result, it was necessary to change some of the open closed questions into semi-closed questions. Semi-closed questions refer to such questions in which the respondents are given a set of fixed alternative responses from which they have to choose an appropriate response and justify their choice. The advantages of the semi-closed questions are: that they allow for comparison between participants' responses or types of participants and also clarify the meaning of questions by providing answers to the questions. They also reduce time allowed for completion of the test as they are easy to complete and to the researcher the responses obtained are easier to process than open-ended questions the responses.

The selected refined responses from the pilot were used to make a semi-closed test. The closed question generated quantitative data as the responses provided numerical data about the quality of TSPCK that teacher displays. All options used as possible answers in the multiple choice questions were based on correct subject matter. The difference was the degree in which a response engages with the question. Respondents were required to choose the best option from a set of 5 options. They were given a chance to explain their choice in provided spaces within the tool as shown in the question below so as to solicit for more quality responses. Below is an example of the draft tool constructed from originally teachers verbatim with modifications as per suggestions by the reference team.

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…..

Figure 4.9: Question drafted from teachers' responses from pilot

Thus the tool remained with the benefits of open-ended questions while also having closed question features, and is considered semi-closed. In all the other four categories remaining the questions were designed in the same format using teachers' comment from the pilot stage.

For the conceptual teaching strategies category, I adapted the question from Pitjeng and Rollick's (2012) self-study paper and used Pitjeng and Rollnick real authentic learner answers from another study to create the context and options for category E. There were seven authentic responses from learners in Pitjeng and Rollnick's self-study of which I only selected four to shorten the test.

All questions left room for further comment by teachers. The question on representations and conceptual teaching strategies remained open ended in nature as well as curricular saliency.

The opinion of reference team was sought to assess and vet the multiple choice questions. The experts checked that each item in the instrument related to what it was supposed to measure, check whether questions are relevant, precise, and are appropriate in length, if there was no ambiguity in questions so that test items would be interpreted correctly by respondents (Creswell, 2012). They also checked if each question in the instrument was in alignment with the five knowledge components of the TSPCK and complexity of electrochemistry content in NCS (DBE, 2011).

Question 4 sought knowledge of the teachers' awareness of the curriculum-curricular saliency. This entailed identification of big ideas in the topic electrochemistry including identification of questions that are taught prior to teaching electrochemistry as well as reasons of the importance of electrochemistry. In the later version, teachers were to identify the reasons related to conceptual development and application to everyday life.

CATEGORY B: CURRICULAR SALIENCY

4.0 Questions 4.1-4.4 relate to planning and sequencing of concepts.

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

Figure 4.10: Sample of question in draft 1 in the pilot study

The question was modified as shown if Fig. 4.10.

Oxidation and reduction numbers	Balancing equations
Electrochemical cells	Electrolysis
Redox reactions	Electroplating processes
Electrical neutrality	Calculation of cell potentials
Electrode potentials	Cell notation
Half-cell reactions	Galvanic cells
Electric cells	Other

List of Topics to be taught before electrochemical cells	**Sequence the topics** (the one to be taught first , place it as No. 1)	**Provide reasons for the proposed sequence**
	1.	
	2.	
	3.	
	4.	

Middle column omitted in the final instrument

Figure 4.10: Sample of question 5 in draft 1 in the pilot study

In the draft question 5, the middle column was removed as per suggestions of the science reference team as shown in Fig. 4.1.

Suggested concepts and sequence	Reasons
1.	
2.	
3.	

Figure 4.11: Modified question in the Final tool

They felt the question was doing two things at the same time- sequencing and looking for pre knowledge. The headings of the columns were rephrased to improve on clarity of demand of the question. The conceptual teaching strategy section had two test items initially. The reference team further suggested that there should be only one question on teaching strategies instead of two as the instrument seemed to be long as shown by the duration taken to complete the tool by the respondents. Based on these recommendations, adjustments and further refinements were made on the tool (see final instrument on Appendix A3).

Question 5.1 was also modified because it seemed to give respondents' problems in terms of responses related to understanding the terms "conceptual progression", "motivation" and "application". In conceptual progression, here, the respondents were supposed to give responses which indicate that the topic on electrochemistry had the potential to build on previous concepts. For motivation, the respondents were expected to give responses that show that the topic is interesting while in the case of application the respondents where to state where electrochemistry is applicable in real everyday life situations for instance in purification of water, battery industry etc. The respondents did not understand what was expected of them under the various headings and this indicated that this was not a good test item or it was ambiguous. Hence, together with the team we agreed that the question should just be open-ended.

Question 4.4 before modification

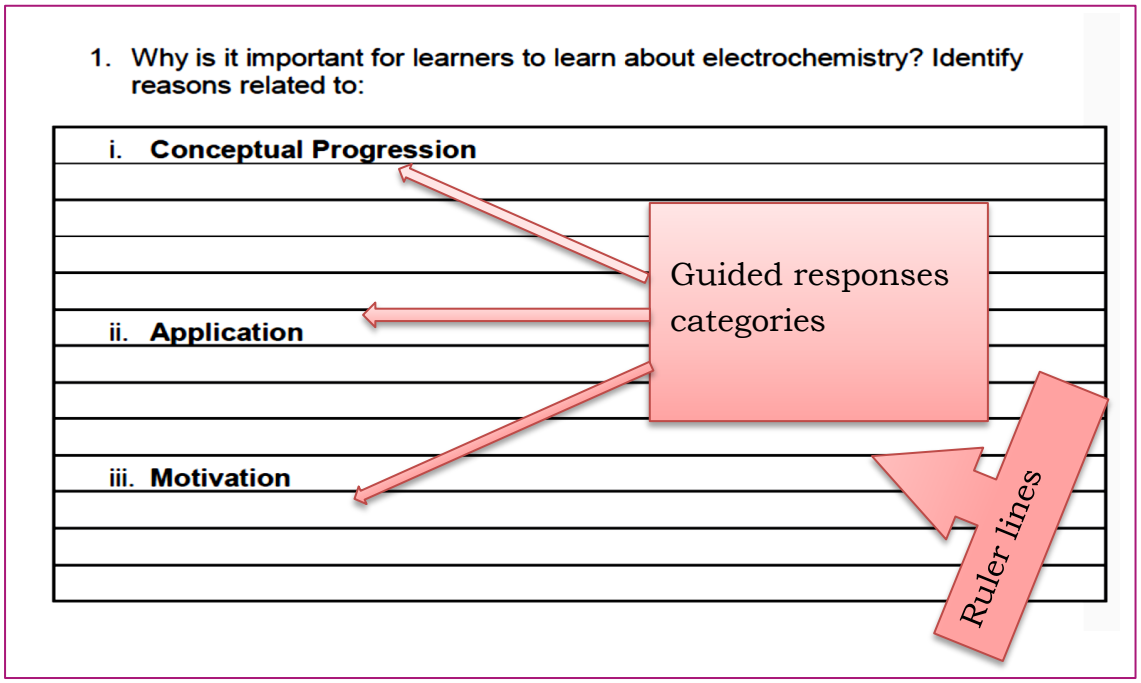


Figure 4.12: Question 4.4 before modification.

Here are some of the extracts of responses for question 4.4 from the piloting of the updated instrument that warranted the modifications.

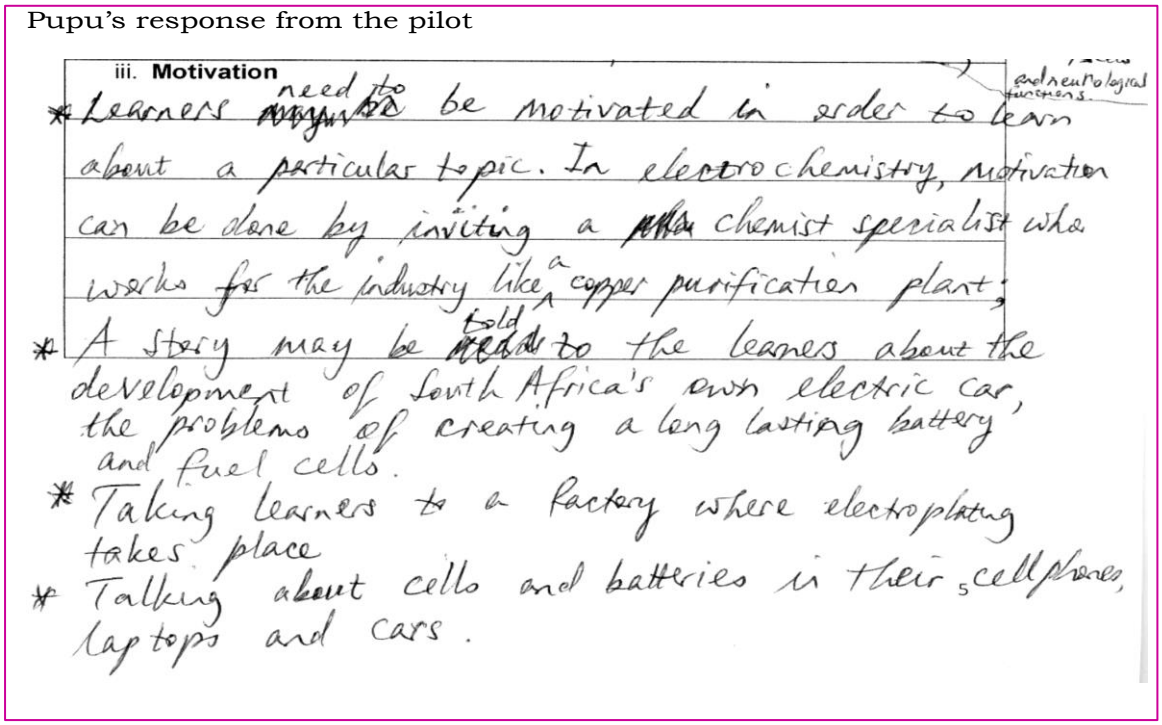


Figure 413a: A response from Pupu from pilot

Zama's response from the pilot

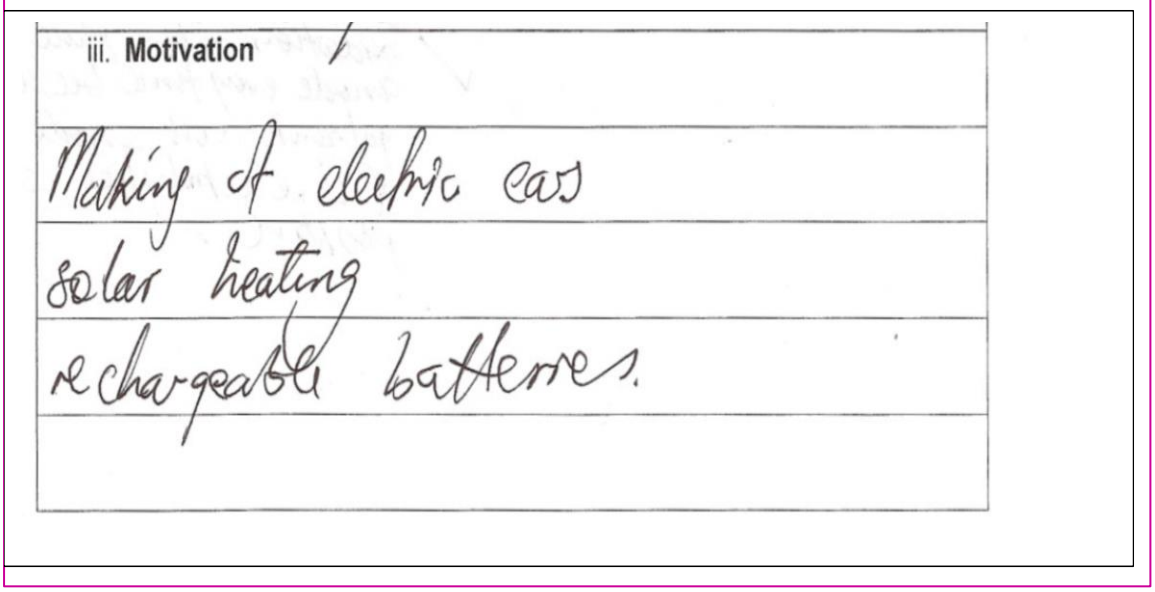


Figure 4.13b: Response from Zama from the pilot study**.**

When looking at the responses by Zama and Pupu to the question to explain the importance of electrochemistry in relation to motivation, it is clear that the two teachers did not understand the demands of the question itself. Zama gave answers related to application instead of motivation while Pupu gave ways to stimulate interest in learners to like electrochemistry. There was confusion displayed in answers given to the three levels of explanation/reasoning as there was mix up of answers and this warranted the recommendations by the reference team to leave the question open-ended in nature. I agreed with the suggestions by the reference team and then I modified the questions follows:

The ruler lines were removed and a blank space was provided. The comments and suggestions from reference team were taken into consideration and the question was modified from Fig. 4.12 above as shown in Fig. 4.14 below.



Figure 4.14: Example of question 4.4 after modification

A number of modifications were made taking into consideration comments from the reference team and the semi-closed version updated tool was then ready for validation which is discussed in the next chapter. The TSPCK instrument was ready to be tested on a large scale on practicing physical science teachers. The validity of the TSPCK instrument was achieved by calculating validity and reliability indices.

4.3 Summary

In this section, a process of development of the final instrument from authentic responses from the pilot was described. In certain categories the questions were converted to semi-closed (as in Category A: Learner prior knowledge) to facilitate reduction of time. A cover page was designed to capture the demography of the participants and a code box was inserted to maintain anonymity and confidentiality of participants as this is ethical. The tool was cleaned by proof reading by the author as well as by the reference group for language purposes. After language edit, hard copies of the TSPCK instrument were made and it was ready for validation. Validation of the TSPCK instrument is discussed in the following chapter. Following below is the description of the process followed in adapting and finalizing the Content Knowledge achievement test.

4.4 The Teachers' Content Knowledge Tool

A conceptual diagnostic test on electrochemistry was used to measure CK of teachers about electrochemistry. This consisted of 21 multiple choice questions in which two of the questions required elaboration of the responses (Appendix A5). The test required the participants to choose a "correct" response from five possible responses given. In addition to best option, question 3 and question 10 required the respondents were to explain their choices. In question 11, the participants were asked to indicate the direction of electrons and the movement of all ions in the voltaic cell. In addition, they were required to identify the positive electrodes. The following section provides a detailed account on the adaptation and modification of the content knowledge achievement test.

In selecting a suitable teacher content knowledge tool, the first step was to define the scope of the content to be covered by the tool. The content evaluated by the diagnostic test included the following concepts of electrochemistry: the electrolytic cells, electrical neutrality, conduction in the electrolyte, cell potential and half-cell reaction, electrode processes and identification of electrodes and products in electrodes using half-cell reactions and calculation of cell potential.

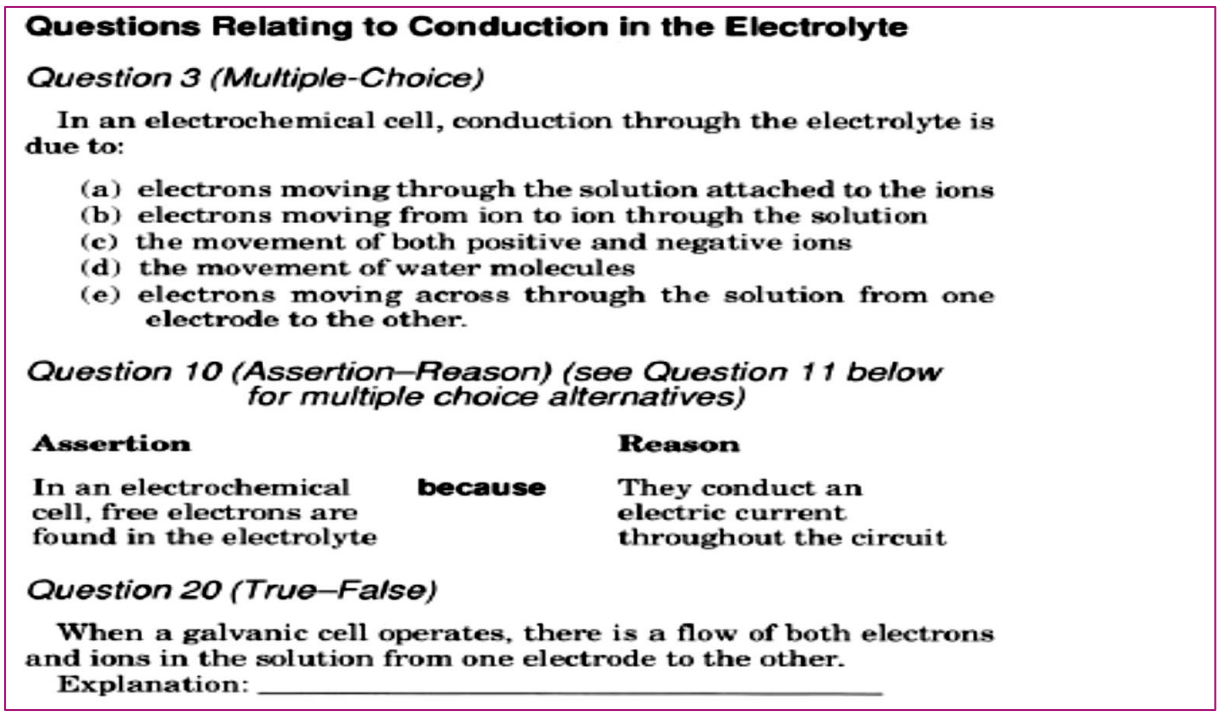
Following recommendations by Creswell (2012), questions were adapted from existing tools or in referenced literature sources for language purposes and because they have been validated already by the authors. These were balanced with the TSPCK instrument. Therefore, the test items are authentic in the sense that they drew from cited literature and grade 12 past exam papers. Most of the questions were adapted from Ogude (1991) and Ogude and Bradley (1994) and grade 12 past exam papers. Therefore, it means that this similar test was administered by Ogude and Bradley (1994) on students to measure their understanding of the electrochemical cells, conduction in the electrolyte and electrode processes and uncover their misconceptions in the topic. However, in this study a similar set of questions was administered because it was assumed that teachers hold similar misconception to their learners (Ogude and Bradley, 1994; Yang, Greenbowe & Sanger, 2002) and

or these misconceptions arise from instruction given by teachers if not from textbook imprints. At first the test consisted of 30 test items.

4.4.1 Modifications of Ogude and Bradley (1994)

Ogude and Bradley (1994)'s test was in form of a questionnaire with 20 test items that were a combination of multiple choice, assertion-reason and true-false items. The test covered four areas on high school or first year university level chemistry. These were: conduction in the electrolyte, electrical neutrality, electrode processes and terminology, and aspects relating to cell components, current, and cell emf (Ogude, 1991 thesis; Ogude & Bradley, 1994). The questions on their paper and pencil test were grouped according to four specific areas aforementioned as shown below and there was a multiple choice test item, assertion–reason item and a true-false test item in each specific area under investigation.

An extract of questions in Ogude & Bradley (1994) showing questions under the areas of electrical neutrality and conduction in the electrolyte is shown in Fig.4.15 below.



Questions Relating to Conduction in the Electrolyte

Question 3 (Multiple-Choice)

In an electrochemical cell, conduction through the electrolyte is due to:

(a) electrons moving through the solution attached to the ions
(b) electrons moving from ion to ion through the solution
(c) the movement of both positive and negative ions
(d) the movement of water molecules
(e) electrons moving across through the solution from one electrode to the other.

Question 10 (Assertion–Reason) (see Question 11 below for multiple choice alternatives)

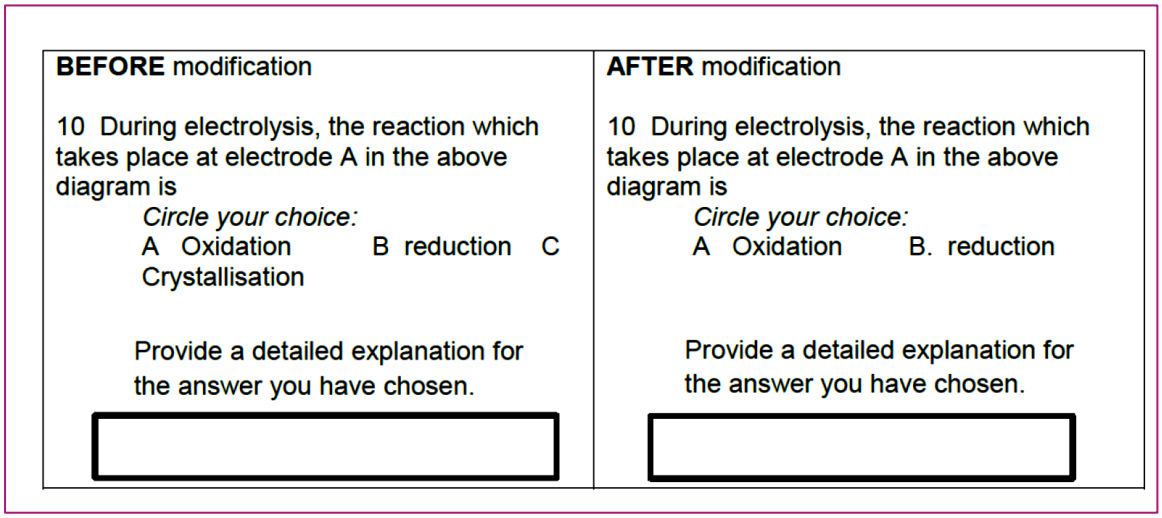
Assertion		Reason
In an electrochemical cell, free electrons are found in the electrolyte	**because**	They conduct an electric current throughout the circuit

Question 20 (True–False)

When a galvanic cell operates, there is a flow of both electrons and ions in the solution from one electrode to the other.
Explanation: _____

Figure 4.15: Sample of questions from Ogude and Bradley's (1994) instrument

The test items were testing similar areas as Ogude and Bradley as these areas present difficulties to both teachers and learners. The difference is that the questions used in this study were not grouped into specific content areas but were scattered throughout the test. The test items were predominantly multiple choice test items, the assertion-reason and true-false questions were not included for the reason that the true-false items increases a possibility of guessing and also assertion–reason items were not familiar to most teachers. Most of the questions were adapted as they are with only a few minor modifications (such as using capital letters for options instead of small letters). Question 10 was modified slightly as the options were reduced from 3 to 2 as shown in Fig. 4.16:



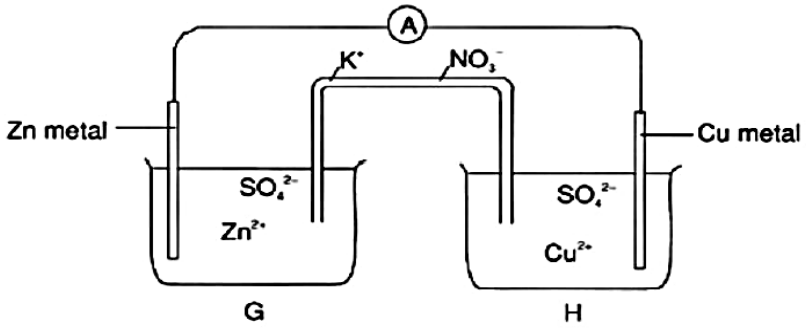
BEFORE modification	**AFTER** modification
10 During electrolysis, the reaction which takes place at electrode A in the above diagram is *Circle your choice:* A Oxidation B reduction C Crystallisation Provide a detailed explanation for the answer you have chosen.	10 During electrolysis, the reaction which takes place at electrode A in the above diagram is *Circle your choice:* A Oxidation B. reduction Provide a detailed explanation for the answer you have chosen.

Figure 4.16: Question 10 before modification and after modification

Option C was left out as it was not a relevant concept when determining electrode processes and reaction in electrochemistry. Question 7 in Ogude and Bradley (1994) had major modifications as shown below.

Question 7 (Multiple-Choice)

In the galvanic cell shown below, as the cell operates, oxidation of the zinc introduces additional zinc ions into half-cell G, and reduction of copper ions leaves an excess negative charge in half-cell H.

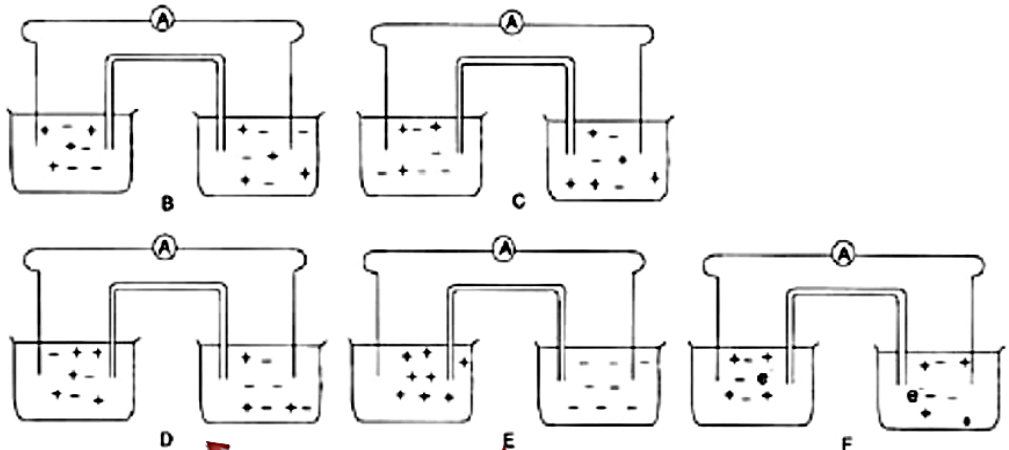


(a) Indicate the movement of all the ions and the electrons.
(b) Which one(s) of the following series of diagrams below depict the change in each half-cell as the reactions proceed?

Note: In the following diagrams, a cation is symbolized as + and anions as –. An electron is symbolized as e–.

(a) Either C and D
(b) E only
(c) B only (d) Either B and E
(e) F only

Option combinations were written in form of capital letters



Originally, the diagrams had alphabetical labels

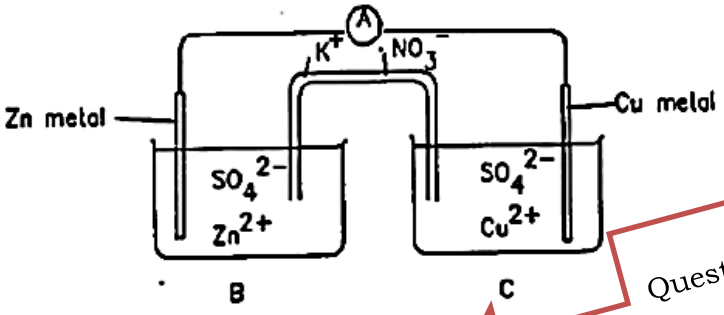
Figure 4.17: Question 11 before modification

The modifications were necessitated by the fact that the multiple choice alternatives in this study were capital letters (A-E) while in Ogude and Bradley used small letters which was not a problem when diagrams were labelled using capital letters. Therefore, there was a need for a different

labelling system on diagrams e.g. use of Roman numerals made it easier to maintain this pattern of capital letters on options. This question was question 11 in the final CK instrument used in this study (see Fig. 4.17).

11. In the galvanic cell shown below, as the cell operates, oxidation of the zinc introduces additional Zn^{2+} into half-cell B, and reduction of Cu^{2+} leaves an excess negative charge in the half-cell C.

a. Indicate with arrows, the movement of all ions and the movement of electrons.

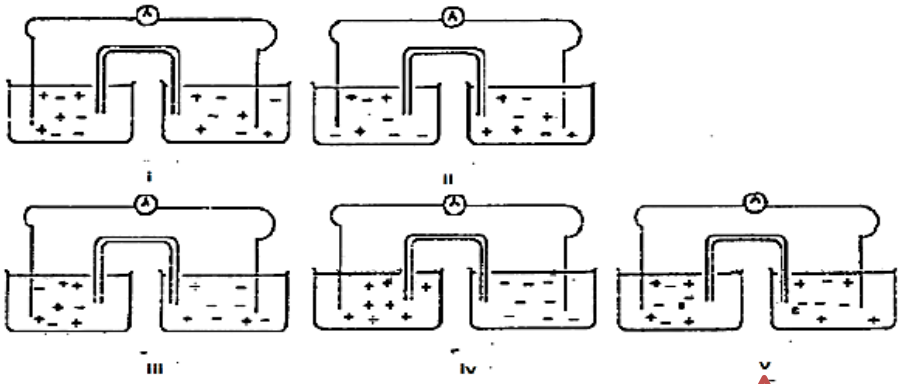


Question b added

b. Label the positive and negative electrodes.

c. Which one(s) of the following series of diagrams below depict(s) the change in each half-cell as the reaction proceeds?

Note: in the following diagrams, a cation is symbolised as + and an anion is symbolised as ▬ An electron is symbolised *as* e^-.



Circle your choice:

A. either i or iii
B. iv only
C. i only
D. either i or iv
E. v only

Option combinations now written in form of Roman numerals instead of alphabetical and also alternatives are written in capital letters

Roman numerals added instead of alphabet labels

Figure 4.18: The modified question in the final CK instrument.

4.4.2 Vetting of the CK Tool

The 30 multiple questions and memorandum were subjected to vetting by the reference team comprised of science education experts in chemistry. The reference team checked the wording and spellings and the content if it is in alignment with the grade 12 electrochemistry assessment standards in the NCS and if answers were written correctly. The reference team suggested that questions that testing similar concepts should be removed and grammatical changes effected. For example, a question testing the function of membrane was removed in the membrane cell. They felt that the salt bridge and the functions of the membrane were similar concepts. For instance, I had written the answer option E wrongly in question 12 as shown figure 4.18 below.

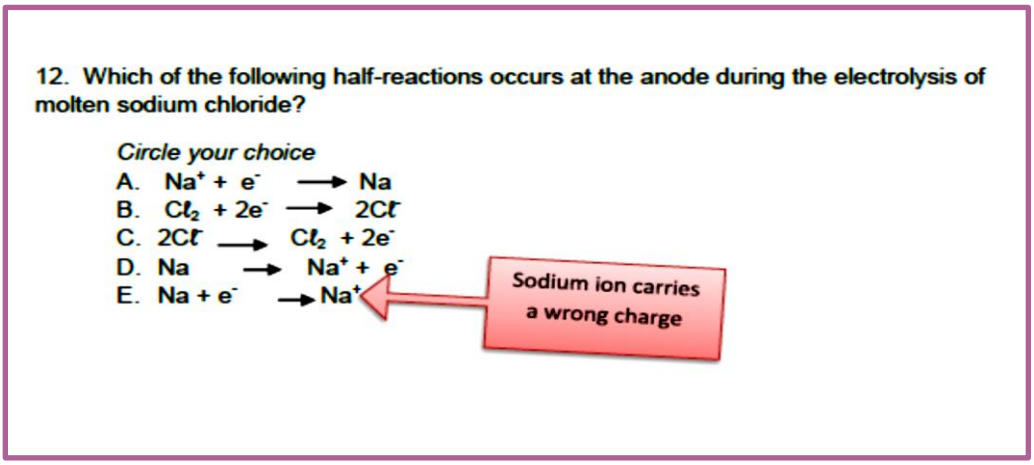


Figure 4.19: Question 12 before vetting

The reference team on vetting the correctness of the construct, they suggested that I should not use wrong concepts in the tests as these would perpetuate the teaching and learning difficulties of electrochemistry an outcry preached in literature and hence corrected the equation to read:

$Na + e^- \rightarrow Na^-$ Sodium ion now carries a correct charge (-) as depicted by the equation

Adjustments were then made to the tool and the memorandum to incorporate the comments and recommendations from the science reference group. After vetting, the questions on the Content Knowledge tool were scaled down to 21 due to removal of questions which were irrelevant or ambiguous questions. Ambiguous test items could give room for incorrect interpretation by the respondents. The test was then ready for a pilot stage and which is described in the next section. Table 4.3 shows the distribution of content/concepts covered by the Content Knowledge test and the sources of questions.

Table 4.3: Distribution of concepts in the Content Knowledge test

Content assessed	**Questions**	**Sources**
Electrochemical cells-	1	Ogude(1991), Ogude & Bradley (1994)
(i) Electrolytic	8, 9, 15,20	
	19, 20	Grade 12 Physical sciences paper (2009)
Galvanic/voltaic	7, 11, 12, 14,	Ogude(1991), Ogude & Bradley (1994)
	18, 20	Grade 12 Physical sciences paper (2009)
Half-cell reactions	2, 5, 12,	Ogude(1991), Ogude & Bradley (1994)
	20	Grade 12 Physical sciences paper (2009
Electrical neutrality	7, 11	Ogude(1991), Ogude & Bradley (1994)
Cell potential	3, 11.	Ogude(1991), Ogude & Bradley (1994)
	21	Grade 12 Physical sciences paper (2009)
Electrolysis	4, 5, 6, 9, 11.	Ogude(1991), Ogude & Bradley (1994)
Electrodes processes	10, 16, 17,	Ogude(1991), Ogude & Bradley (1994)

4.4.3 Piloting the draft content knowledge tool

An approved draft tool with 21 multiple choice items were piloted with 3 experienced physical science teachers after taking ethical issues into consideration in order to determine how long it takes to complete the test and check its reliability. The teachers were given time to write their responses and the time taken to complete the test by each respondent was approximately 90 minutes. Adjustments and refinement were made as informed by the pilot results.

4.4.3.1 The final content knowledge tool

A final content Knowledge tool was then administered at a large scale to 21 practicing physical science teachers. This was an attempt to answer the last research question:

- What is the relationship between the measured quality of their Topic Specific PCK of teachers and their content knowledge in electrochemistry?

The test was marked using the memorandum and it is in Appendix A5. To assure validity, the independent peer validators scored the tests independently to check if the scores I awarded were consistent with theirs and also the explanations given by the respondent were scientifically correct. The content knowledge test is in Appendix A4.

4.5 Summary

A TSPCK achievement test was developed and used to measure the physical science teachers' topic specific PCK while the Content Knowledge achievement test was adapted, modified and used to measure their content knowledge. The development of the TSPCK instrument followed method used by Rohaan *et al.* (2009) who used the following steps in a chronologically order: production of test items, judgment of items, construction of the instrument, piloting and construction of the actual instrument and finally, validation of the instrument in conjunction with steps outlined by Treagust (1988). Both instruments were piloted with

practicing physical science teachers as a step to ensure the validity and reliability of the instruments. The results from the pilot phase were used to develop and update the TSPCK instrument. Face validity of the TSPCK test items as well as adapted content knowledge test items was ascertained by an established science reference team. A reference team comprised of professionals in science education chemistry consisting of the two project supervisors and myself. In addition two to three experienced practicing teachers were added to the reference team. The reference team assisted in establishing content validity and aspects related to the accessibility of the language of the tool. The developed TSPCK instrument and the modified Content Knowledge instrument were found to have valid content and TSPCK test items and these were then subject to various tests for construct or instrument validity and reliability.

The next chapter discusses how validation of the TSPCK instrument was carried out to ensure that that the instrument is valid and reliable. Also presented is the construction of a TSPCK rubric which was used as a rating scheme. This was done to address the research question two set out in chapter one.

Chapter 5
Validation of the TSPCK Instrument

The previous chapter outlined the steps used in the development of the TSPCK instrument and the Content Knowledge instrument. This chapter looks at the issues of validity and reliability of the developed TSPCK instrument and the Content Knowledge tool. I first describe the design of the TSPCK rubric. Secondly, I give an interpretive argument followed by a validity argument which supports the argument for consideration of TSPCK as a theoretical construct. Then, I discuss how the TSPCK rubric was used in scoring the responses from the instrument. Finally, I deliberate on the process followed to validate the TSPCK instrument using the Rasch statistical package for analysis.

5.1 Introduction

Validity is an issue that has been of concern in most educational and social science research. The terms validity and reliability are used to establish the quality of research instruments. For any instrument to be considered useful, it should produce data that is trustworthy and meaningful so that the results obtained could be generalised in other settings (Creswell, 2012). This implies that newly developed instrument should undergo validation to check their authenticity. Validation therefore is a process of assessing authenticity and dependability (Creswell, 2012) of the means used to collect data. In a case where an instrument is used, validation ascertains whether the instrument yields data that is measuring what is being intended. In this study, a new topic specific pedagogical content knowledge (TSPCK) instrument was developed therefore, the need to validate it. Findings from this chapter serve as a response to answer research question number two enlisted below:

- How valid is the developed instrument in measuring as sample of physical science teachers in Gauteng schools?

In this study, both the validity and reliability of the test scores collected were established through the use of the Rasch model. In the section that follows, I discuss how the TPSCK rubric was designed and validated.

5.2 TSPCK rubric

A PCK rubric was used to mark the teachers' responses and as a rating scheme for the instrument. According to Park & Oliver (2008), the PCK rubric is a set of criteria used to measure the teacher's level of PCK based on teacher's observations while teaching and during observation interviews. The TSPCK rubric was designed and used in another study on the topic chemical equilibrium where it was shown to have acceptable validity and reliability scores (see Mavhunga & Rollnick, 2013). The TSPCK rubric was however, constructed to have five categories in line with the content specific components in the theoretical framework (see Chapter 2 section 2.4). Fig. 5.1 below shows the extract from the TSPCK rubric used in the study.

TSPCK Components	Limited(1)	(2) Basic	(3) Developing	Exemplary (4)
Learner Prior Knowledge including misconceptions	No identification/No acknowledgement /No consideration of student prior knowledge or misconceptions 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
	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 5.1: Extract from TSPCK rubric used in the study

Modifications were done on the authors' TSKfT rubric to suit my study and see detailed modifications on Appendix A11. The complete TSPCK rubric is attached as Appendix A12. The TSPCK rubric was validated by the reference group to check its alignment with the five categories of TSPCK as well as appropriateness of descriptors. The reference group suggested that the descriptors should show progression from one response category another e.g. from 'Limited' to 'Exemplary". Comments from the reference team were taken into consideration, modifications were made as suggested and a final rubric was ready to be used as a score sheet. The discussion that follows shows the argument for validity, followed by how the Rasch model determines validity.

5.3 Establishing TSPCK as a theoretical construct (Construct validity of TSPCK instrument)

Different authors have defined validity in different ways but what emerges from the different definitions there is a shared understanding of what validity is. Below are various definitions of validity from literature.

Creswell (2012, p.159) described validity as the correctness of conclusion we draw from the gathered data while Messick (1989, p.6), on the other hand, claims that validity is an integrated evaluative judgment of the degree to which empirical evidence and theoretical rationales support the adequacy and appropriateness of inferences and actions based on test scores or other modes of assessment. Moreover, Kane (2006) takes validity to be a property of proposed interpretations and uses of test scores.

In light of the various definitions, there are common themes that emerge from each definition that ensures the validity of data: correctness, appropriateness of inferences or conclusions drawn from test scores/data and Messick added judgement as an additional criterion. Therefore, raw scores from teachers collected by the instrument will also be judged using a similar criterion. Validity answers the question: is my instrument measuring what is claimed to be measured?

Since there are various definitions of validity, for this study, I adopted the definition by Messick (1996) because in validation of the TSPCK instrument, I would check if the empirical evidence agrees with theoretical predictions which are outlined in section that follows below. Literature indicates that the process of validating an instrument differs in respect of what aspect of validity is being judged. Since there are many ways of validating instruments, for this study, the validity of the tool is argued based on the principles that guides construct validity, which requires both interpretive and statistical validity analysis as arguments. The discussion that follows presents interpretive argument of TSPCK construct.

5.3.1 Interpretive argument of construct validity of TSPCK

In beginning my *interpretive argument* I made these theoretical claims:

1. TSPCK is a construct that exists as an entity within a topic and is separate from PCK in a discipline (see discussion in section 2.4).
2. TSPCK is different from PCK in the sense that if focuses on transformation of content concepts at the level of a topic, different from the generic PCK which maybe at a domain (chemistry) or subject level (science) (Veal and MaKinster, 1999).
3. Transformation of concepts at topic levels results from the collective knowledge and interaction of five content specific components (see components in section 2.4).
4. The conceptual teaching strategies component is more difficult when compared to other components.

These claims then formed my theoretical framework which is part of my interpretive argument. In Chapter 2, when using the Topic Specific PCK model as a theoretical framework I was defining what the construct is and how it different from other PCK. The discussion has been provided in Chapter 2, section 2.4. As mentioned in Chapter 4, the key features of the TSPCK instrument are that it was designed according to five components of TSPCK. Each component was regarded to be category and it formed a test item (see a detailed discussion in chapter 4).The section that follows unveils how the process of validating the developed TSPCK instrument (developed in chapter 4) was carried out.

5.3.2 Statistical validity argument of construct validity of TSPCK

In *validity argument*, I argue for statistical validity of the instrument. As said earlier, the Rasch scores would determine validity, when the Rasch scores agree with the theoretical prediction, then the instrument would be valid. I argue that *'If the test score is a valid manifestation of TSPCK (words changed), so conceived, its relations to other variables conform to the theoretical expectations'* (Cronbach, 1971, p.462). For validity argument for TSPCK as a construct, I will look for evidence from the Rasch analysis that

supports not only the theoretical implications of the score meaning in the teachers' responses but will also look at the implications of the Rasch scores obtained.

Therefore, validity in the Rasch statistics model centres on the idea that the noted performances are manifestations of a single fundamental construct, in this case TSPCK. The Rasch statistical software provides two indices of fit, the Infit and the Outfit. According to Linacre (2012), this fit statistic is based on the difference between a person's observed score on a subset of items and the score on that subset as predicted by the person's overall ability estimate. A conventionally statistically range of -2 and +2 indicate that items and persons are a good fit, acceptable and are both measuring a single construct (Bond & Fox, 2001). *Infit* statistics indices focus on the general performance of an item in the instrument or person responses to the test items. It is a summary of the discrepancies between an observed and expected performance. If there is a positive correlation between the measured person ability and item difficulties as intended by the test, therefore, this signifies the construct validity.

On the other hand, *Outfit* displays items that are slightly beyond the person's capability (Boone and Rogan, 2005, p.34). Linacre (2012) says that it is an outlier-sensitive fit statistic that picks up rare events that have occurred in an unexpected way. Linacre furthers asserts that it is the mean of the squared standardized deviations of noted performance from the expected one. In this study if the items and person scores are within the range of -2 and +2, this would be an indication of an acceptable validity. This would imply that both the items and the person scores consistently work together to measure a single construct-TSPCK. The fit statistics is displayed in Fig. 5.2. The Rasch statistical value range of -2 and +2 indicates a goodness of fit to the model. This implies that both items and persons must fall within this range to indicate the validity of the TSPCK construct and hence the developed the TSPCK instrument.

5.4 Analyzing the final tool for statistical construct validity

The semi-closed version of the TSPCK instrument described in chapter 4 was validated with practicing physical science teachers. The instrument measures the quality of PCK for teaching electrochemistry hence the reason for selecting teachers who have many years of teaching and have taught electrochemistry, since PCK is thought to be acquired by experience

5.4.1 Participants

The final tool was administered on a larger scale to a convenience sample of about 21 physical science teachers teaching in various schools in Johannesburg for purposes of establishing its validity and reliability. This included teachers who are doing honours degree in science education specialising in physical sciences at the University of the Witwatersrand whom I approached during their lecture and administered the instrument in person. As per ethical requirements, the participants were informed about the purpose of the study and they signed the consent form. I personally explained the objectives of the study and how it would benefit them. During the explanation, the teachers were asked to answer as honestly as possible and attempt all the questions. I administered the TSPCK which took 80 minutes to complete. The environment was calm and relaxed. The participants seated themselves randomly in their usual places as this was their lecture theatre and were spaced in such a manner that answering of questions was an individually effort with no discussions. I told the teachers that they were free to ask questions where they were not clear about the test items. Here some of the questions which they asked by the participant as they were clouded with an attitude of reluctance to write.

What will happen if we fail this test? Are our chemistry lecturers going to see these results? *Are we going to be graded using this test?*

I assured them that the promises made in the consent form would be maintained and none of their identity would be disclosed. In addition, I told them (participants) that the test would not be graded but used for research

purposes only. The next section gives a description of how scoring was carried out using the TSPCK rubric.

5.4.2 Scoring process and validation of the scores

I first marked the physical science teachers using an approved TSPCK rubric. I analysed the responses in light of their engagement with the question and then graded each teachers' responses that matched a certain criterion according to the TSPCK they displayed. For validity purposes of the scores as mentioned in section 3.5.3, I invited independent peers to rate the teachers' responses from the TSPCK instrument as well and they agreed. This was done to check if rating was consistence with theirs, that are going to give the similar scores for the same response or not. I should make this explicit that the independent peer raters were not the same reference team I consulted during rubric construction. The peers consisted of one doctoral student and one physical science teacher who have many years of teaching electrochemistry at grade 12 level and was also doing a Master's degree. Both were registered at the University of the Witwatersrand. The doctoral student was doing similar research involving instrument design, and therefore I assumed that the peer could be very familiar with PCK issues and the TSPCK rubric criteria.

Before scoring, the independent raters were acquainted with the TSPCK instrument, with the rubric criteria as well as the rating criteria. After they had familiarized (peer raters) themselves with the rubric, the criteria for scoring and their expectations explained, two independent peer raters individually scored the instrument using the rubric as I sat with them. Where they had uncertainty with the classification system I clarified the issues. The scores were compared and discussions were held on the scoring. For example, I awarded a score of 3 in the category of what is easy or difficult to teach to a teacher who had just identified topics s/he considered difficult in teaching. On comparing the scores, the independent raters felt that the teachers should be awarded a 2 (not a 3) as the explanation given as to why the concept is difficult was hazy. Eventually we made a final agreement on which score to award. Where differences occurred these were

resolved through discussion. An overall rating agreement of about 85% was obtained, an indication of the reliability of the scoring of the tool. The final raw scores of the physical science teachers' scores are summarized in Table 5.1.

Table 5.1: Physical science teachers' raw scores

Person	Learner prior knowledge	Curricular saliency	What is difficult or easy	Representations	Teaching strategies	Average TSPCK scores
MN01(Lolo)	3	3	3	2	2	3
MN02 (Ben)	2	2	2	1	1	2
MN03(Dola)	3	2	2	1	1	2
MN04(Sammy)	3	2	3	2	2	2
MN05(Sheena)	3	2	2	1	1	2
MN06(Kashmiri)	3	3	3	3	2	3
MN07 (Greg)	3	2	3	2	2	2
MN08(Suku)	3	2	3	3	2	3
MN09 (Susan)	3	2	2	2	2	2
MN10(Andy)	3	2	2	2	1	2
MN11(Theme)	2	2	2	1	1	2
MN12(Gugu)	3	2	3	2	2	2
MN13(Edwin)	2	2	2	2	1	2
MN14(Tiane)	3	2	2	2	2	2
MN15(Shelton)	2	1	2	1	1	1
MN16(Vusi)	3	2	3	3	1	2
MN17(Mbali)	3	3	3	2	2	3
MN18(Leon)	4	3	3	3	2	3
MN19(Frank)	4	3	3	3	1	3
MN20(Xola)	3	3	3	3	3	3
MN21(Shannon)	2	3	3	3	3	3

To get insight of the overall quality of topic specific PCK on the topic of each individual teacher I found the mean scores of the categories. The table above

shows that the majority of the physical science teachers displayed Basic PCK (rating of 2). They gave poor quality responses. This implies that their responses only met criterion 2 in the TSPCK rubric, for example in the case Learner Prior Knowledge, in which they (teachers) did not only fail to identify the error made by the learners but also failed to give a strategy which is effective in remedying the error and move the learner towards understanding of the concept. However, the table only shows the final rating of answers but not the criterion which was met for such a score to be awarded. When the validation of the scoring process was complete, the raw scores were then analysed with the Rasch statistical model. This is discussed in the next the section.

5.4.3 Converting raw scores into Rasch

The raw scores from the rubric were subjected to the Rasch analysis using Winsteps MINISTEPS version 3.75.0 which converted the scores to a probability scale of equal interval enabling the calculation of the item and person reliabilities (Bond & Fox, 2001). In short, the Rasch model converts ordinal data (raw scores of performance from rubric) to interval data (linear scores). The teachers' raw scores were subjected to the Rasch model as explained in the earlier sections which converts raw scores into probability scores. The formation of probability scores is premised on the perception that easy items are likely to be answered correctly by all persons taking the test including low achievers while difficult test items are most likely to be answered correctly by persons with high ability (Bond & Fox, 2001). Since the tool was newly developed its validity was not known and hence the Rasch scores would give an indication of construct validity of a questionnaire (in this case the test). The Rasch model also summarises completely a person's standing on a variable for instance TSPCK in this study or CK as well as providing estimates of internal consistency. In Fig. 5.1 is a summary person statistics of the physical science teachers sample scores from Rasch model to show person measure order, i.e. from the highest ability to the lowest ability.

Person	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD
MN20 (Xola)	7.72	1.31	1.98	1.4	1.49	.8
MN18 (Leon)	3.09	1.28	.65	-.5	.34	-.2
MN19 (Frank)	3.09	1.28	2.15	1.8	3.33	1.5
MN06 (Kashmiri)	1.56	1.22	.24	-1.2	.20	-.7
MN21 (Shannon	1.56	1.22	3.45	2.2	2.70	1.4
MN01 (Lolo)	.16	1.15	.51	-.8	.34	-.5
MN08 (Suku)	.16	1.15	.89	.0	.58	-.1
MN17 (Mbali)	.16	1.15	1.64	1.1	1.80	1.0
MN04 (Sammy)	-1.15	1.15	.32	-1.2	.24	-.4
MN07 (Greg)	-1.15	1.15	.32	-1.2	.24	-.4
MN12 (Gugu)	-1.15	1.15	.32	-1.2	.24	-.4
MN16 (Vusi)	-1.15	1.15	2.20	1.6	2.22	1.1
MN09 (Susan)	-2.54	1.21	.37	-.9	.23	-.4
MN14 (Tiane)	-2.54	1.21	.37	-.9	.23	-.4
MN03 (Dola)	-4.11	1.27	.16	-1.1	.13	-1.0
MN10 (Andy)	-4.11	1.27	.16	-1.1	.13	-1.0
MN13 (Edwin)	-4.11	1.27	.16	-1.1	.13	-1.0
MN02 (Ben)	-5.50	1.09	.60	-.6	.45	-.5
MN05 (Sheena)	-5.50	1.09	.60	-.6	.45	-.5
MN11 (Thamu)	-5.50	1.09	.60	-.6	.45	-.5
MN15 (Shelton)	-7.85	1.22	.46	-.8	.29	-.2
MEAN	-1.37	1.19	.87	-.3	.77	-.1
S.D.	3.55	.07	.87	1.1	.92	.8

Person reliability	0.89	
Item reliability	0.96	
Fit statistics	+2 and -2	Most Rasch values are within +2 and -2 except for MN21

Item measure mean set to zero & Units per Logit (log-odds unit) =1 for the entire test (UIMEAN=0 and USCALE =1)

Figure 5.2: Person STATISTICS: Person measure (N=21)

Figure 5.2 show that the sample of teachers found the test slightly difficult as indicated by a mean performance of -1.37 (SD = 3.35). The more positive are the person measures, the higher the ability of that individual and vice-versa. This result also gives an indication of the validity of the developed instrument, since *Infit* and *Outfit* statistics is within the range of -2 and +2 with the exception of teacher MN21 whose *Infit* and Outfit values is greater than two**.** This is indicated by parameters Infit ZSTD and OUTFIT ZSTD on the headings (see also Fig. 5.3 for visual display). The ZTSD values are used as a t-test. The ZSTD (also called z scores) have a mean of 0.

The mean square (MNSQ) values further provide evidence of the validity of the instrument (see Fig. 5.2). The MNSQ values of less than 1 show dependence on the data collected using the TSPCK instrument (Linacre, 2012). From Figure 5.2, the mean square values are less that 1 with the exception of just a few values which are above 1. A detailed discussion on how Rasch established the validity and the reliability of the developed TSPCK instrument follows below.

5.4.4 Interpreting the Validity and Reliability Statistics of the Rasch

5.4.4.1 Fit statistics as evidence of validity of the TSPCK instrument

The above descriptions of instrument measures of validity are going to be used as a basis of results analysis for this study. On plotting the performance of teachers to the five test items-categories of TSPCK, the following is a bubble map was obtained. The bubble map in Fig. 5.3 shows the person and item Infit and Outfit.

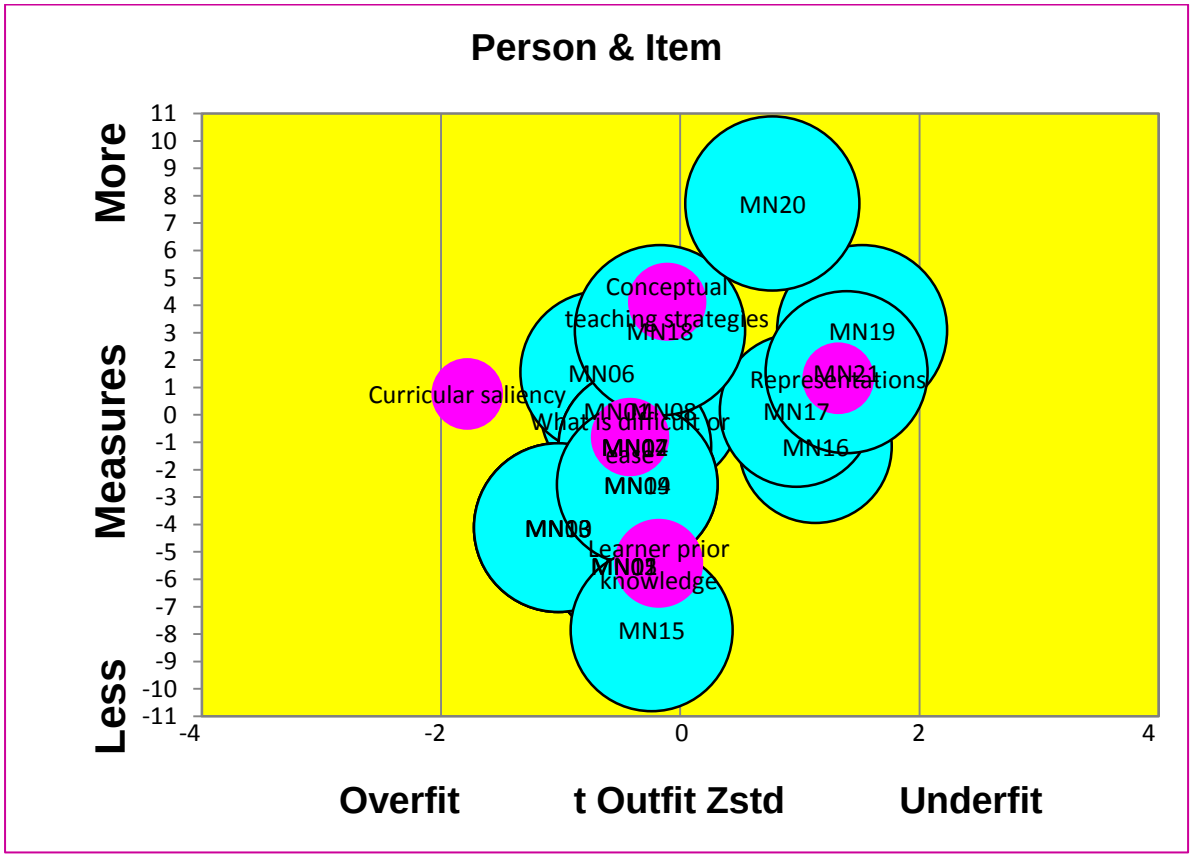


Figure 5.3: The Person and Item map

Figure 5.3 shows that the person and the item fit statistics of the practicing physical science teachers, fell well within the accepted traditionally range of -2 and +2 as measured along the x-axis with the exception of teacher Frank (MN19) and Shannon (MN21). This implies that data works together to measure a single construct, the instrument is valid as evidenced by the significant measured good fit. This in turn signifies that both the persons and the items measured a single construct which is topic specific TSPCK**.** The blue bubbles represent person probability measures and the pink ones represent the item difficulty measures respectively. Moreover, the person item map also indicates the person abilities and test item difficulty (see Table 5.3). The Y-axis shows the ascending order of measures of persons' ability as well as the order of difficulty of test items. Referring to the claim made earlier, the more the difficult the test item the higher the probability that a person with higher ability will answer it and vice versa. From Figure 5.1, we can see that the bubbles are of different sizes. The implications of the different sizes of bubble are discussed in section 5.5.3. As indicated above, teacher Shannon fell outside the -2 and +2, the reasons are that the teacher did not answer the questions probably she ran out of time. This made her to have values greater than the Outfit statistics of greater than +2 denoting under fitting responses. These teachers provided better quality answers in other test items. Following below is a brief summary of the performance of teachers in the different categories of the TSPCK instrument.

5.4.2 Evidence from the difficulty ranking of TSPCK components

In the interpretive argument (section 5.2), it was postulated that the Conceptual Teaching Strategies component is the most difficult as compared to the other four components. The Rasch model besides calculating the person and item reliability, it also calculates the empirical hierarchy difficult order of the five TSPCK components. The summary statistics from the Rasch Model is summarised in Table 5.2.

Table 5.2: Item difficulty rank of TSPCK categories

Learner prior knowledge	What is easy or difficulty	Curricular saliency	Representations /models	Conceptual teaching strategies
<	<	<	<	<
-5.42	**-0.81**	**0.76**	**1.34**	**4.13**

Item measure mean set to zero & Units per Logit (log-odds unit) =1 for the entire test (UIMEAN=0 and USCALE =1)

The item difficulty hierarchy generated by the Rasch statistical package ranked the Conceptual Teaching Strategies category the most difficult and Learners' Prior knowledge category as the least difficult (see Appendix 14 for detailed item summary statistics). This confirms the theoretical postulation that most practicing teachers usually struggle in the conceptual teaching strategies component of TSPCK than in learner prior knowledge category. This means that the conceptual teaching strategy is of higher order only persons with higher ability could answer such test items. The reason for difficulty experienced in conceptual teaching strategies is probably because it draws from all the other knowledge components. This means that the individual should draw from all the knowledge components and bring them together, by this I mean that s/he should have sound knowledge of learner's prior knowledge including misconception, know the concepts that are easy or difficult to teach and sequence them for appropriately, what representations to use during instruction as well as the teaching strategies. In short, the teacher should reason using all the five components in order to teach for conceptual understanding. In category the "What is difficult or easy to teach" most of physical science teachers could not provide justification for their answers they gave to those test items which they identified as difficult. From the bubble map the least difficult item is placed at the lower bottom of the bubble map while the hardest item is found at the top. In other words, the more negative the test item is, the least difficult is that item and vice-versa.

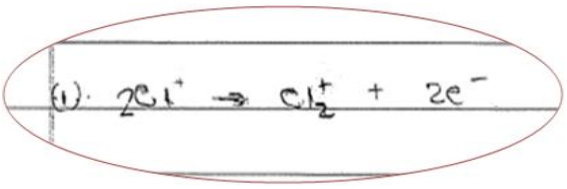
It was worth noting that the conceptual teaching strategies ranked as assumed in the interpretive argument (see Table 5.3) and this also is a testimony to the construct validity of the TSPCK instrument. This in line with argument put forward by Wright & Masters (1982, p.93) that when the empirical expectation agrees with theoretical one, it means that the instrument is valid.

On the item difficulty rank order, the representation category was ranked second highest in the hierarchy. This might be attributed to the fact that teachers hardly use models or representations in practical investigation in classroom environment for teaching for conceptual understanding. Probably most lessons on electrochemistry are taught theoretically and only textbooks diagrams for voltaic and electrolytic cells are used for explanations. The TSPCK categories were demarcated as explained in the earlier section due to different demands of the questions. The ranking of TSPCK categories is similar to the one obtained by Mavhunga and Rollnick (2013). The difference is that in their study with practicing teachers on the topic chemical equilibrium they found that representations and curricular saliency category were ranked equal while this study showed that representations category was more difficult than curricular saliency. This could have been attributed by the nature of topics that demanded different application of subject matter knowledge. This is in line with observations cited in literature that PCK is topic specific.

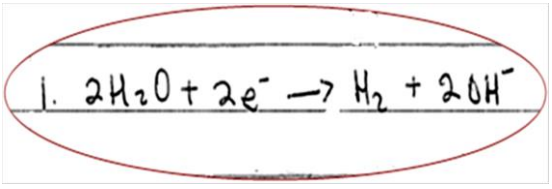
The following section provides examples of responses from the final TSPCK instrument to show the quality of the data collected using the developed instrument. Only areas of concern are going to be discussed. Fig. 5.4 shows an extract of the question under the Conceptual Teaching Strategies category (see the complete question in Appendix A3). These responses were from learners from the study by Pitjeng and Rollnick (2011). Learners were to identify the products of the anodic reaction on electrolysis of brine.

The learners provided the answers below:

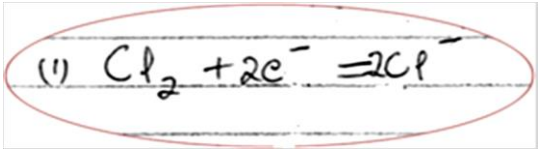
Extract 1



Extract 2



Extract 3



Extract 4

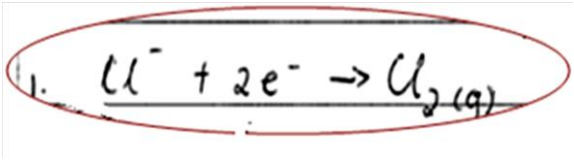
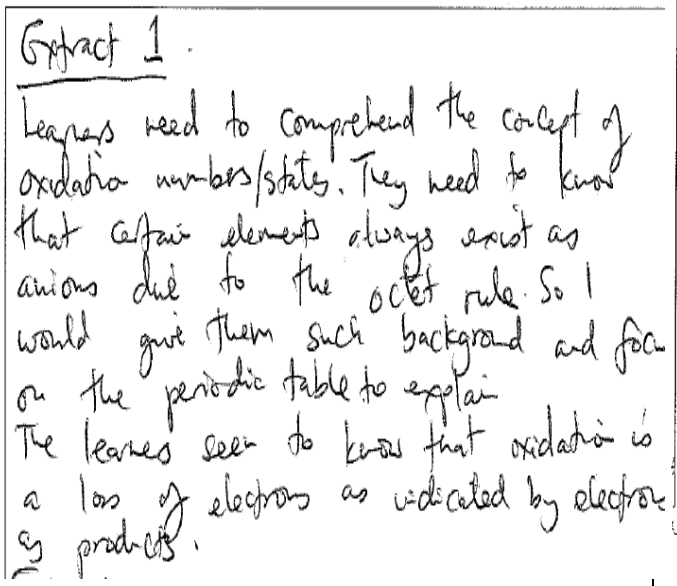


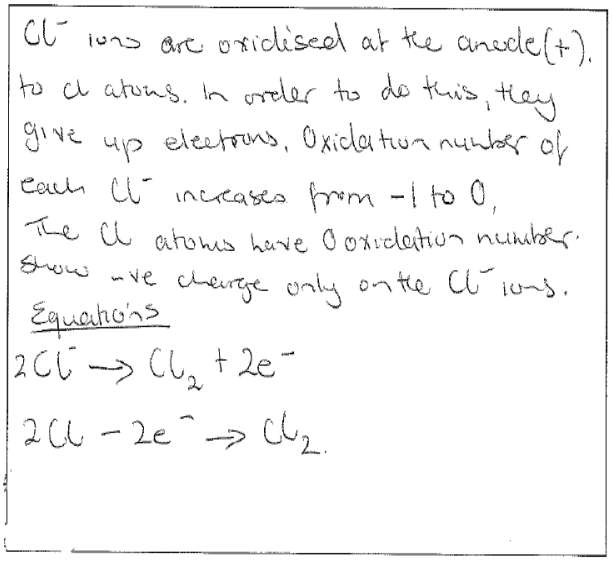
Figure 5.4: Extract of question 7 under Conceptual Teaching Strategies

The participants were supposed to identify the error made by the learners and provide an explanation to correct the incorrect concept. Below are some of the responses obtained from the participants in the study.



Extract 1.

Learners need to comprehend the concept of oxidation numbers/states. They need to know that certain elements always exist as anions due to the octet rule. So I would give them such background and focus on the periodic table to explain. The learners seem to know that oxidation is a loss of electrons as indicated by electrons as products.



Cl^- ions are oxidised at the anode(+). to Cl atoms. In order to do this, they give up electrons. Oxidation number of each Cl^- increases from -1 to 0, The Cl atoms have 0 oxidation number. show -ve charge only on the Cl^- ions.

Equations

$2Cl^- \rightarrow Cl_2 + 2e^-$

$2Cl - 2e^- \rightarrow Cl_2$

Frank's response (MN18)

Frank has Limited TSPCK as demonstrated by his failure to answer the question. On evaluating Frank's response it is clear that the teacher may not have understood the

Suku's response (MN08)

Suku partially answered the question, she did not point to the error made by the learner on each situation but the teacher made a general explanation of anodic

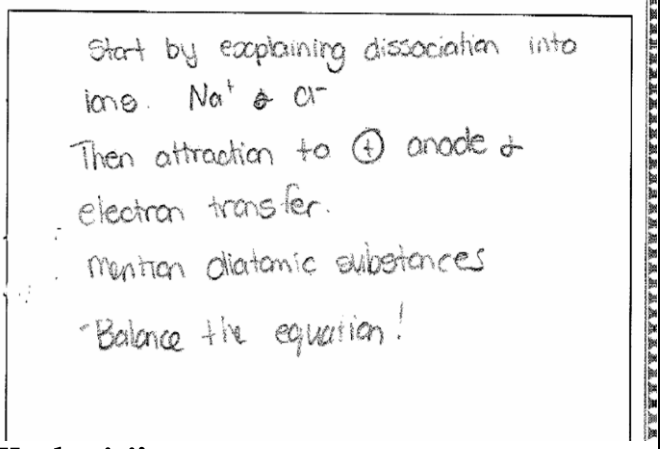
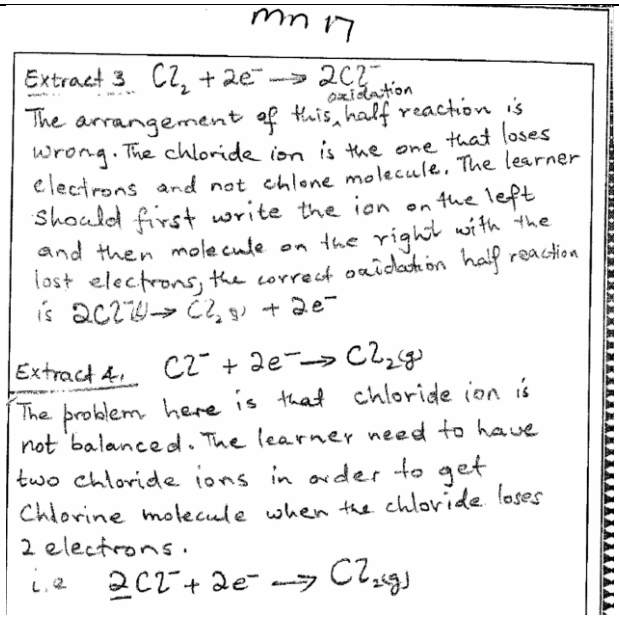
question itself. Frank did not point out to the error made by the learner in each situation and also failed to provide specific instructional strategies to correct the learner's error so that the learner could move towards the correct concepts of understanding the electrode process. He gave a general approach on how he was going to teach oxidation concept.	reactions and the products formed. The teacher even went on to correct at least one of the equations. Therefore, Suku was classified as having 'Basic' TSPCK. She did not display exceptional teaching strategies that could make the learners understand electrolysis of brine better and the products formed at each electrode.
 **Kashmiri's response** Kashmiri exhibited Limited TSPCK as shown by the response to the question. The teacher could not identify the error made by the learner and even try to correct the learner instead she gave an approach she could follow to teach the concept. The teacher might not have understood the question itself.	 **Mbali's response (MN17)** Mbali demonstrated a clear understanding of the question and displayed Developing PCK. Although the teacher managed to identify the error made by the learner and correct it, the teacher however, did not demonstrate a strategy that is exceptional in teaching Mbali's response the concept.

Figure 5.5: Responses of teachers to question under the Conceptual Teaching Strategy category in the final TSPCK instrument

Fig. 5.3 indicates that participants struggled with the Conceptual Teaching Strategies category as postulated in the interpretive argument. The quality of responses obtained in this category as displayed in Fig. 5.5 attests to the result in Fig. 5.3. Most teachers did not provide quality answers and quite a number (9 out of 21) exhibited Limited TSPCK as they left the question unanswered (see Table 5.1 for raw scores). This indicates low quality of TSPCK in this category. This is also the sign of the validity of the instrument when empirical evidence agrees with theoretical predictions. See Fig. 5.9 for further confirmation.

The teachers in the study also struggled a lot with the Curricular Saliency category test items. Fig. 5.6 shows an extract of sub-question 4.1 which required participants to identify the big ideas in electrochemistry and then give a reason for the identified sequence.

A question in the Curricular Saliency category:

Suggested concepts and sequence	Reasons
1.	
2.	
3.	

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 ideas[1] for your students to understand by 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.

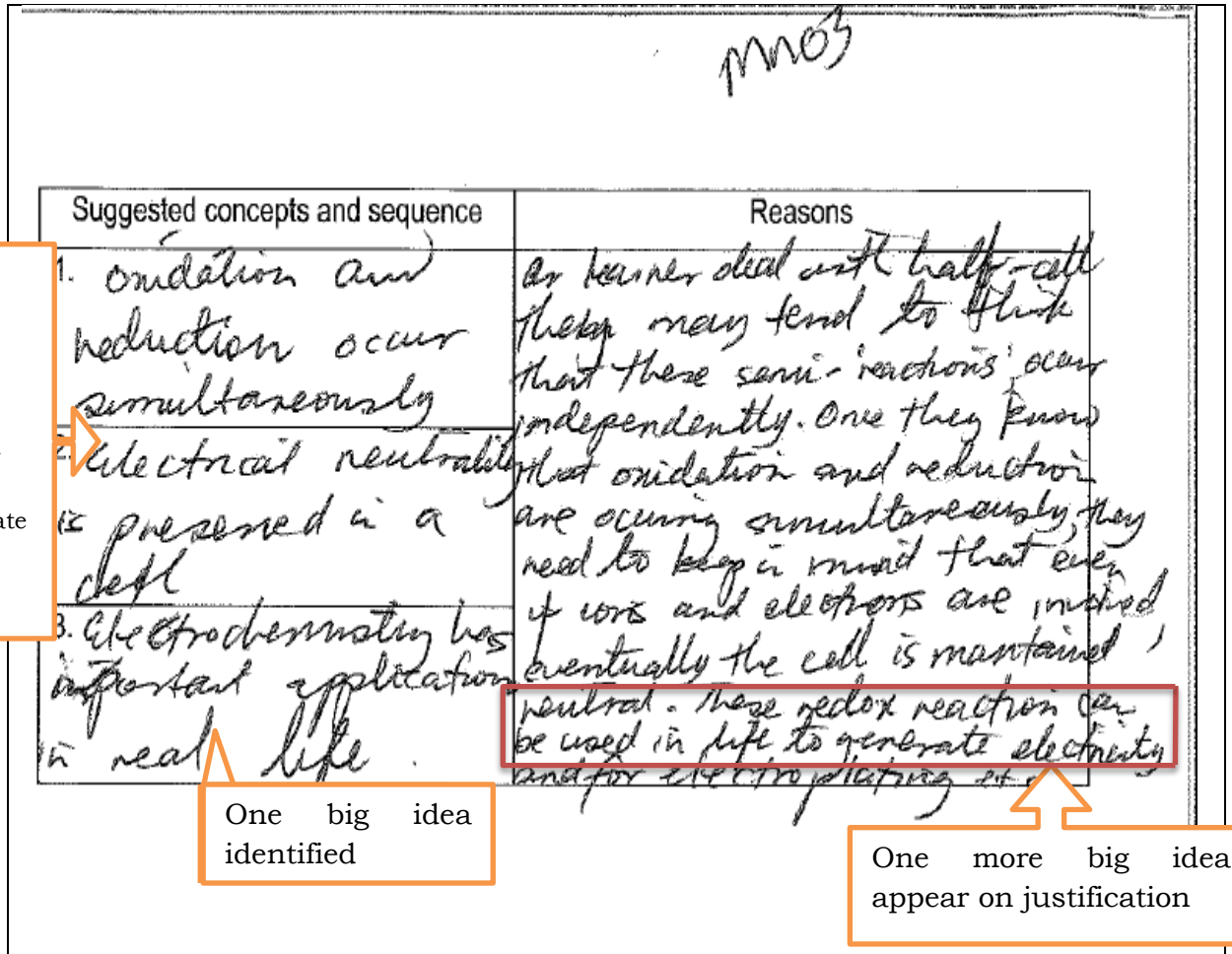
Oxidation and reduction occur simultaneously.	Equations must be balanced
Energy from chemical reactions produces electricity	Electrochemistry has important applications in everyday life
Electrical neutrality is preserved in a cell	Electroplating processes use redox reactions
Electrode potentials are 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.

Figure 5.6: Extract from question 4 under Curricula Saliency Category in the final TSPCK instrument

The participants were rated depending on the number of big ideas identified and providing a plausible explanation for sequencing them in a certain order. Fig. 5.7 and Fig. 5.8 illustrate the difficulty faced by some teachers in the knowledge of the curriculum component.

Extracts from participants' responses are shown in Fig. 5.7 below.



Dola' s response

From Dola's response, it is clear that Dola was aware of the gate-keeping concepts in the topic but however, they are mixed with subordinate concepts. Dola identified at least one big idea but was categorised as having Developing TSPCK (according to the rubric criterion, the teacher should have fallen under Basic TSCPK). Despite confusing big ideas with subordinate ideas, the teacher showed awareness of main concepts in the topic as evidenced by one more big idea appearing in his explanation and hence given a rating of 3. The teacher may have not understood the question very well.

Suggested concepts and sequence	Reasons
1. Electricity can be used to produce a chemical reaction	- basis of electrolytic cell
2. Energy from chemical reactions produces electricity	- principle behind operation of galvanic cells
3. Electrochemistry has important real life applications	- the important links between the concepts and real life.

3 big ideas identified

Xola's response (MN20)

Xola identified three big ideas and justified the sequence for the choice,thus, met most criterion of rating 4 on the TSPCK rubric. The teacher is aware of the gate keeping concepts in the topic of electrochemistry suggesting that she might be teaching for conceptual understanding as she reasons through the knowledge of the curriculum. This is sign of good quality of TSPCK. Hence, Miss Xola was classified as having Exemplary TSPCK on this knowledge component of TSPCK.

MN19

Suggested concepts and sequence	Reasons
1. Definitions of oxidation, reduction, electrolyte, electrode, and electrochemical cells	ELECTROCHEMISTRY ALWAYS INVOLVES THE TRANFER OF ELECTRONS) THROUGH SOME OF THESE PROCESS MATERIAL
2. Galvanic cells	TYPE OF electrochem cells where Ch → Electr. energy are used daily in all appliances common.
3. ELECTROLYTIC CELLS	always easier to tackle once learners have understood the (portaneous and non-spanta. process.

Only topics identified

No big idea identified

Big ideas appear on reasons

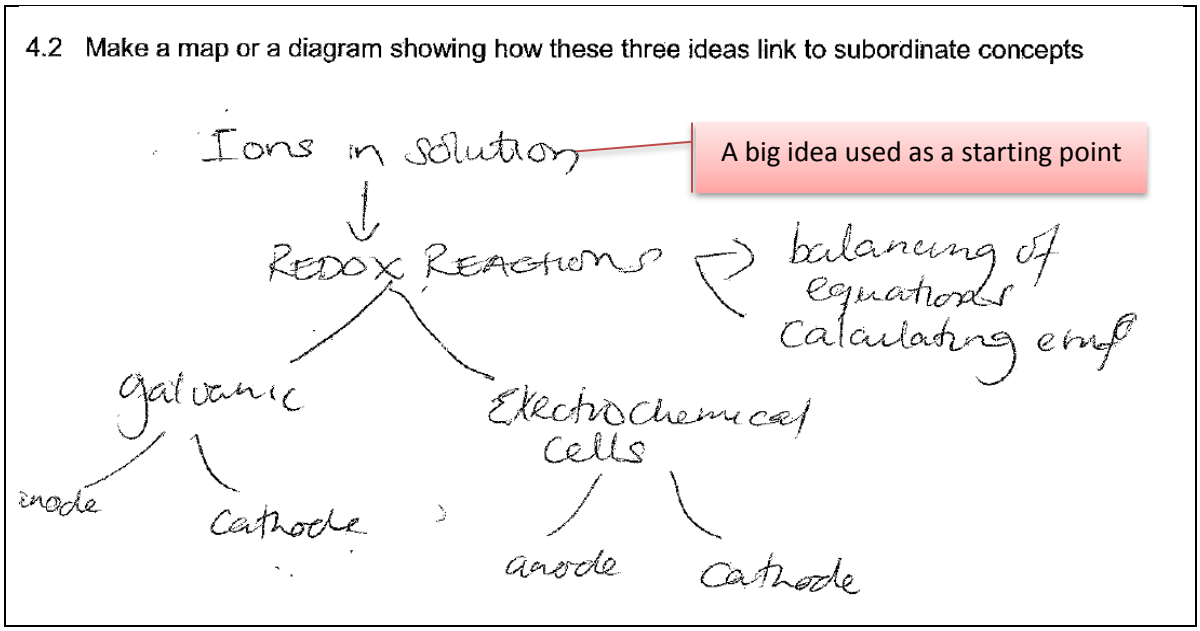
Frank' s response

On analysing the response from Frank it is worth noting that Frank did not identify any big ideas instead he listed the topics which was not what the question demanded. However, the big ideas appear in the reasons for using such a sequence. Lack of awareness of gate keeping concepts is a sign of poor quality of TSPCK and therefore, the teacher exhibited Limited TSPCK. Probably, Frank could not have understood the question it self.

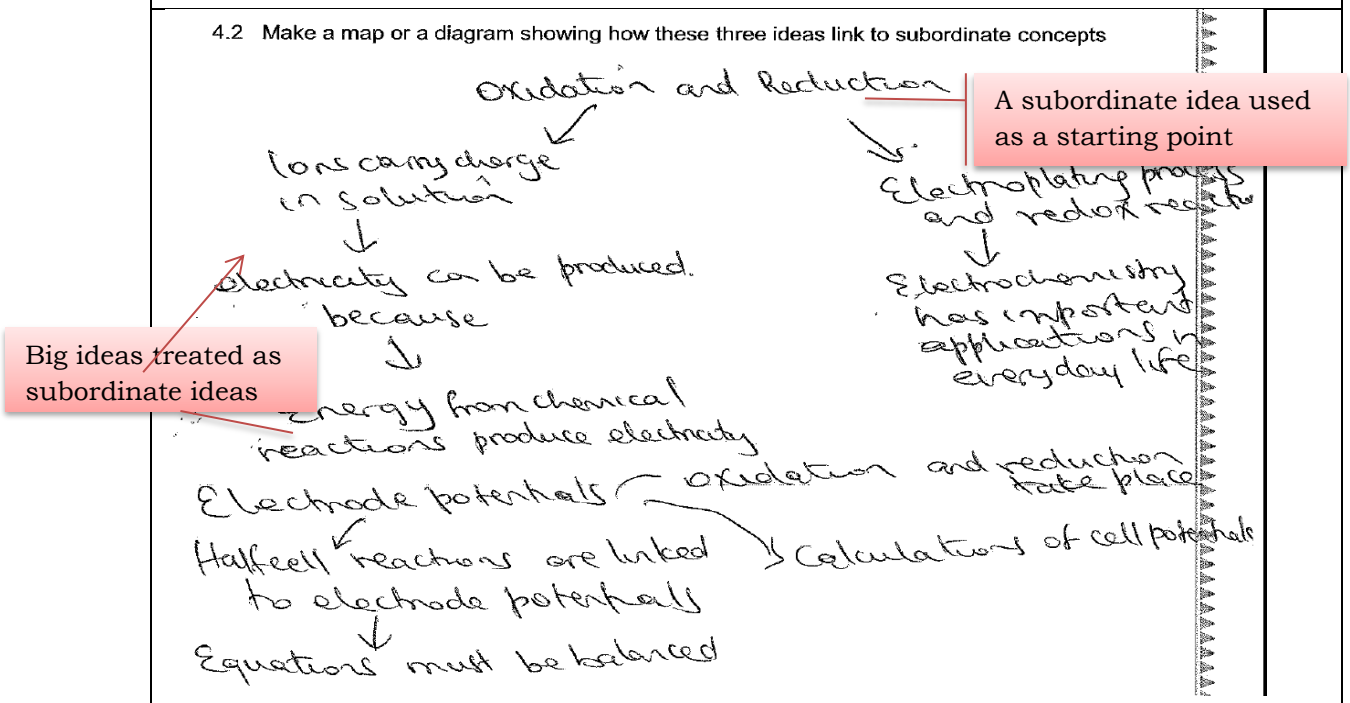
Figure 5.7: Responses to question 4.1 under Curricular Saliency Category in the final TSPCK instrument

On this test item, the difference between Xola, Frank and Dola was that Xola demonstrated the awareness of the curriculum as shown by his awareness of the big ideas and gave the better reasons for his choice. On the other hand, Dola and Frank although there is evidence from their reasons that they know the big ideas, their responses showed poor knowledge of curricular awareness issues as they appeared to mix up big ideas and topics to be taught.

Still on the Curricular Saliency category, sub-question 4.2, some of the physical science teachers displayed poor quality responses and thus poor quality PCK in linking the big ideas identified in 4.1 with other subordinate concepts in a concept map. Fig. 5.8 shows extracts of teachers' responses in the test item 4.2.



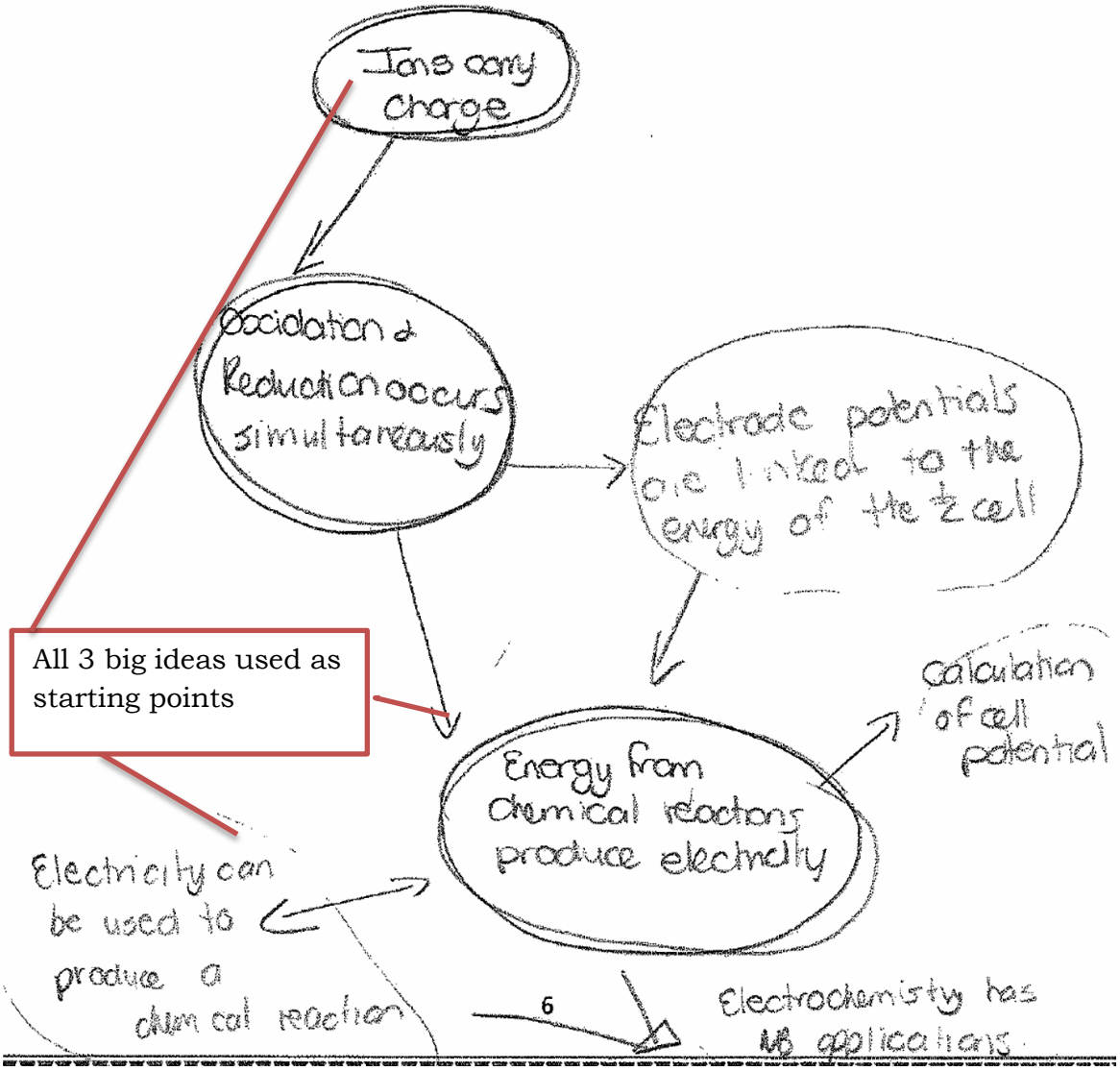
Shannon (MN21) was classified as having Basic TSPCK as she could show how the big idea she identified in 4.1 links with other concept. The most striking part was that Shannon used the big idea as the starting point to draw her concept map. This provides evidence that Shannon's TSPCK still at knowing the basic concepts of electrhochemistry and is not yet developed. Shannon might not be teaching learners for conceptual understanding but for mastering of facts.



Lolo (MN01)'s response

Lolo exhibited Basic PCK although the concept map shows quite a number of big ideas in electrochemistry and their linkage with subordinate concepts. Lolo seem to be confused between the big idea and sub-topics in electrochemistry. For instance, she had a notion that oxidation and reduction was the big idea and then all other concepts were derived from the this concept. For this reason her concept map used a subordinate concept as a starting point. Despite this misconception, it is pleasing to note that Lolo was very much aware of the big ideas and this is a sign TSPCK is at its developmental stages. The teachers could be teaching for concceptual understanding.

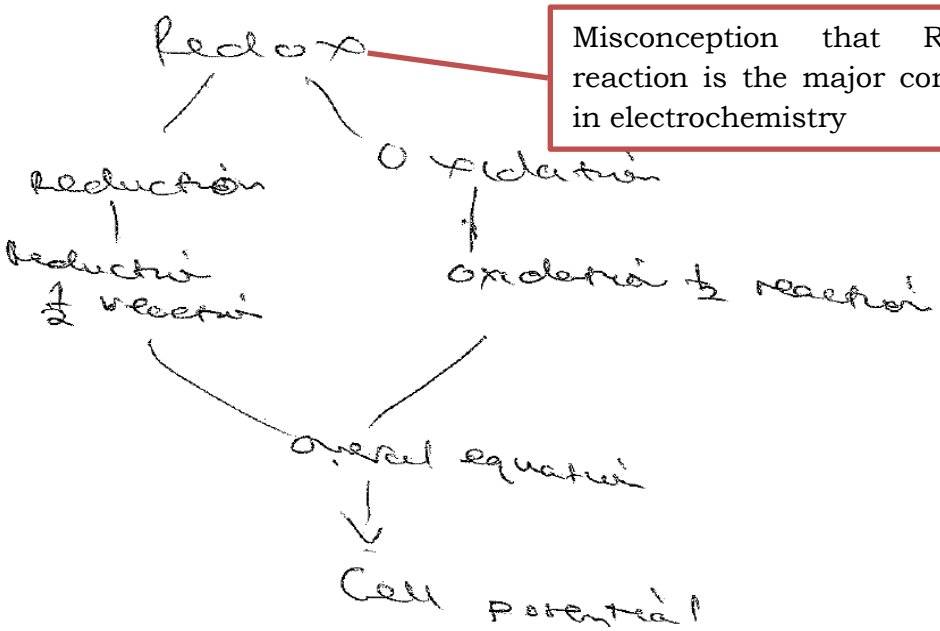
4.2 Make a map or a diagram showing how these three ideas link to subordinate concepts



MN06 (Kashmiri)'s concept map

Kashmiri exhibited Developing TSPCK in this category as she managed to show how big ideas are linked to each other and to other subordinate ideas. This map is different from that of Shannon as it shows depth of understanding of the gate keeping concepts and their linkage with other concepts in the topic of electrochemistry.

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



Sheena's concept map

Sheena's concept map does not have any of the big ideas but a Redox reaction and related subordinate topics. She may not have understood the question itself. The teacher might be having a misconception that electrochemistry is all about Redox reactions yet there are many chemical reactions taking place. This shows a decline in the quality of TSPCK as compared to other respondents with their extracts discussed above

Figure 5.8: Responses of some participants to test item 4.2 in the Curricular Saliency category in the final TSPCK instrument

On evaluating the concepts maps of Kashmiri and Lolo, one can argue that both have identified at least 3 big ideas in their maps but how did they come to be placed in different categories of TSPCK? The answer is that the question required them to show how the identified big ideas in test item 4.1 are linked with subordinate concepts. Using big ideas as a starting point in drawing of the concept map was a measure of the quality of TSPCK (i.e. whether the response demonstrates Limited, Basic, Developing or Exemplary TSPCK) as well as a measure of whether teacher reasons through the knowledge of curriculum . Therefore, Lolo's response is different from that of Kashmiri in respect of that Kashmiri used a big idea(s) as a starting poing

while Lolo used a subordinate concept. Shannon (MN21) and Kashmiri (MN06) used big ideas as the starting point, but the level of engagement with the question made them to be classified as having Basic and Developing PCK respectively. Kashmiri's concept map shows interconnectedness of concepts while Lolo's map exhibits a linear relationship between the concepts. This shows an improvement of the quality of TSPCK on the part of Kashmiri when compared to Lolo. Overall, Kashmiri, Lolo and Shannon were all rated as having Developing TSPCK (see Table 5.1) on the Curricular Saliency category despite their responses to this particular test item. This is because of the fact that they provided good quality responses in other sub-questions under this category. Their weaknesses in one sub-question was balanced by their strength in the other sub-questions. The above responses provide further evidence that the developed TSPCK instrument could measure the differences in qualities of topic specific PCK of physical science teachers and hence it is valid.

5.4.4.3 Reliability of the instrument

Reliability of a research instrument is the ability of the instrument to give the same outcome whenever the instrument is administered to similar participants in other similar contexts (Joppe, 2000). This means that a reliable instrument gives steady scores every time it is used (Creswell, 2012). The Rasch statistical package also was used to determine the reliability of the instrument.

Basically, there are two reliability indices that are provided by the Rasch model as compared to other statistical software packages such as Cronbach's alpha. These are of the person taking the test as well as the one for items contained in the test. According to Linacre (2012), a reliability index indicates the reproducibility of relative measure location.

Wright and Masters (1996) points out that the *person reliability* index indicates reproducibility of person ordering if the same persons would answer another set of items measuring the same construct. A high *person*

reliability index shows that scores are well spread from low to high and hence a good spread of scores by persons in the sample that took the test. This implies that confidence can be placed on the consistency of deductions or conclusions drawn from the study. According to Bond and Fox (2001, p.32) the *item reliability* index denotes the reproducibility of item ordering if these same items were given to another similar sample of respondents. Bond and Fox maintain that high *item reliability* gives an indication that the developed tool had both easier and difficult and thus confidence can be placed in the inferences. Coupled with these reliability indices, are item and separation indices. The separation indices are uses to classify people according to their abilities while item separation indices are used to verify item difficulty hierarchy (construct validity). *Item separation* index of greater than 3 and item reliability>0.9 are quite acceptable to confirm item difficulties hierarchy (construct validity). On the other hand, person separation index>2 and a person reliability index>0.8 are quite acceptable to confirm person abilities i.e. high achievers from low achievers (Linacre, 2012, p. 574). In this study, the person and item reliability indices of 0.8 and above are acceptable to show reliability of the TSPCK instrument.

5.4.4.3.1 Reliability of the TSPCK instrument

On analysing the scores from the rubric using the Rasch analysis, very good reliability indices were obtained for the TSPCK instrument and these are shown in Table 5.3.

Table 5.3: Person and item reliability (N=21)

Person Reliability	Item Reliability	Cronbach's Alpha (KR-20)
0.89	**0.97**	**0.84**

Item measure mean set to zero & Units per Logit (log-odds unit) =1 for the entire test (UIMEAN=0 and USCALE =1)

The internal consistency of test items as measured by Cronbach's alpha (KR-20) value were found to be acceptable as a score above 0.5 is usually the accepted degree of consistence. Cronbach's alpha KR-20 value = 0.84

indicated the high internal consistency of the test items. The detailed summary is in Appendix A13.

The person reliability index is acceptable as it above 0.8 although most teachers are clustered at the lower vertical scale in the person-items map. This signals poor ability in answering PCK test items. The high person reliability index (>0.8) (Linacre, 2012) shows that the developed instrument is reliable, meaning that a different group of similar teachers would get similar scores. A high person reliability index indicates a good spread of person abilities across the scale (high to low).

On looking at the item performance in the instrument, an item separation of 5.26 (see Appendix A13) was obtained confirming the item hierarchy. According to Linacre (2012, p. 574), a low item separation of less than 3 coupled with low item reliability (<0.9) suggests low item difficulty. For this study, 0.6 is used as a critical point, 0.7 upward are acceptable values on a scale of 0-1. Generally, a low person reliability (<0.8) indicates that the instrument might not be quite sensitive to discriminate between high achievers and low achievers (Linacre, 2012). In this situation low separation of items, could be clustered around a high difficulty value.

As explained in earlier sections of this chapter, the Rasch statistical model provide two measures: that of a person taking the test and that of the items difficult hierarchy**.** When the item and persons measure is plotted a person-item Map shown on Fig. 5.9 is obtained.

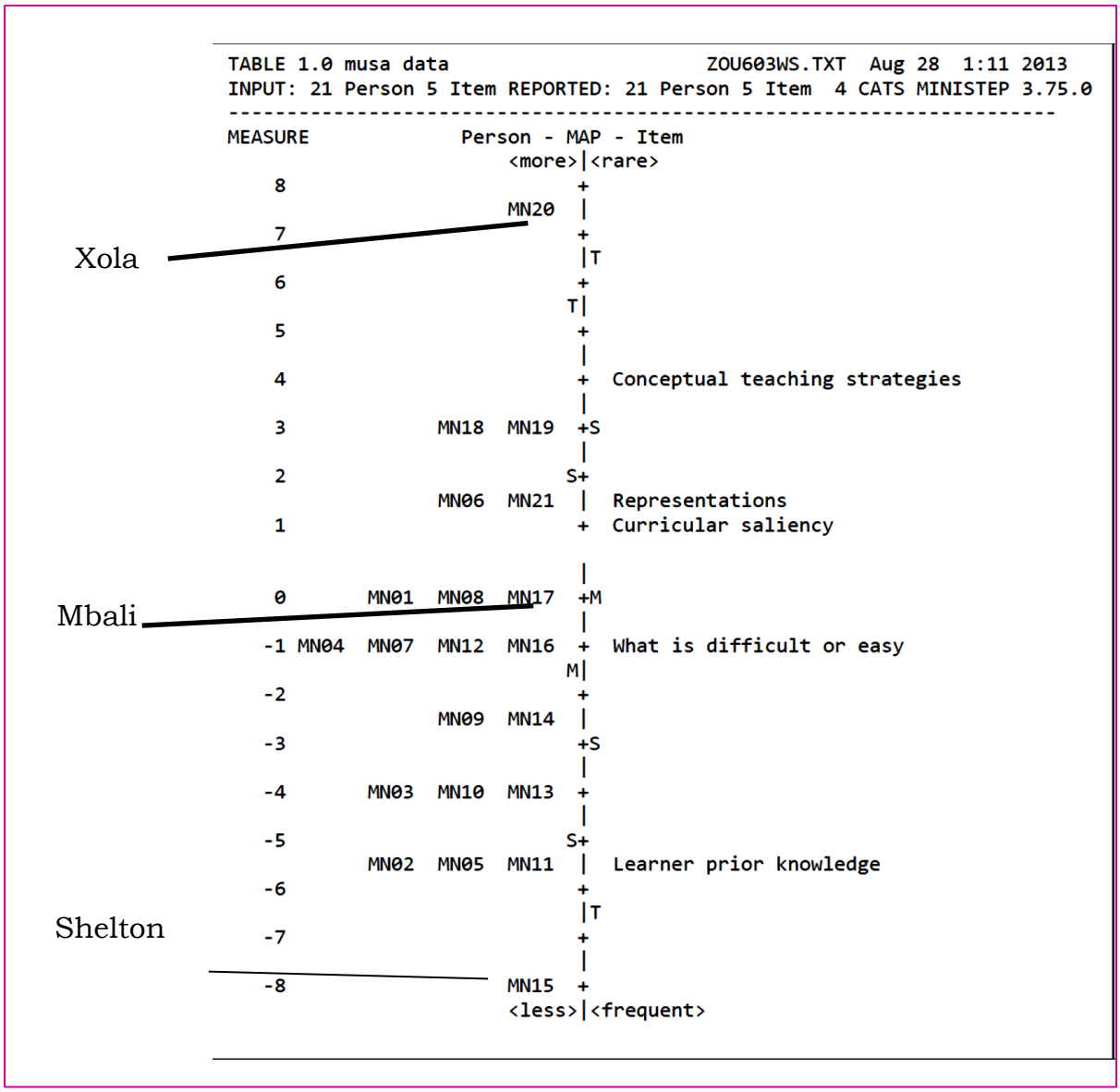


Figure 5.9: Item-Person measure map (N=21)

The Rasch scores further confirm the observations made when analyzing the responses from teachers that most physical science teachers struggled in with the conceptual teaching strategy component of TSPCK. The reason could be the fact that in order for the examinee to answer the questions in this category, s/he has to draw from all other knowledge components of the TSPCK, i.e. from Learners' prior knowledge, curricular saliency, What is difficult or easy to teach and Representations. S/he should pull the entire knowledge component together for him or her to be able to answer the questions from the conceptual teaching strategy category. From the item map, it is clear that all the participants did not give good quality answers to

all questions. The majority of the participants were not able to answer the questions fully and some did not even attempt to answer the questions. To be precise, Mbali (MN17) had better quality answers to test items in the categories: Learner Prior knowledge, What is difficult or easy to teach, Curricular Saliency but had lower quality answers in the Conceptual Teaching Strategies. It is interesting to note that teacher Xola (MN20) demonstrated an overall better quality topic specific PCK as measured by the TSPCK instrument to all the test items including the test items in the conceptual teaching strategies. This confirms the theoretical postulations that a person with higher ability is able to answer difficult test items. This indicates the validity the developed TSPCK instrument since the theory (interpretive argument) agrees with empirical evidence (statistically validity argument) from the Rasch model.

As predicted in the interpretive argument (section 5.1.1.2), it is striking to note that the minority of physical science teachers could effectively answer questions on conceptual teaching strategies thus indicating a poor quality of PCK. This implies that the physical science teachers in this test sample could not be teaching this topic of electrochemistry for conceptual understanding. When the interpretive argument (see assumption 3, section 5.1.1.2) agrees with empirical validity argument, this provides evidence that the developed instrument is valid. From the person- item map, it is evident that the instrument is valid as it could distinguish between persons with high ability and those with lower ability as well as item difficulty hierarchy. As for item difficulty measures, the more positive the test item measure is, the more difficult the test item is and the higher the chances that persons with higher probability measure could answer that test item.

Also evident in Figure 5.3, is that the person measure probabilities are clustered and overlapping. This results in the formation of fairly large bubble sizes and hence indicating a good reliability in the respondents' responses. The persons with larger bubbles sizes usually signal inconsistency in their responses (e.g. MN21) while those with smaller bubbles display high consistency in their responses and a high reliability in

their location. However, the sizes of the bubbles got slightly smaller higher up the vertical axis, indicating a higher probability of answering difficult items and thus high reliability. This was in line with arguments put forward by Linacre (2012, p. 574) who argued that a *'high reliability' of persons or items means that there is a high probability that persons (or items) estimated with high measures actually do have higher measures than persons (or items) estimated with low measures*. Linacre further recommends that in order to get a high reliability, either use a wider sample or have a low measurement error. So he suggests that if you want high person reliability, you need to use a person sample with a large ability range and if you want high item reliability use an instrument with many items. Following the suggestions by Linacre, the study reveals that developed TSPCK instrument had fairly test long items and the sample had a fairly large ability and therefore, these high item and person reliability indices obtained. Both the items and persons measured the same construct which is TSPCK.

In addition to the item and reliability measures discussed above, further evidence of the instrument reliability is shown in the person-item bubble chart in Fig. 5.3. According to Boone and Rogan (2005), the size of the bubble generally indicates the degree of error in locating individual persons or items along the vertical scale. Boone and Rogan further states that the larger bubbles show lower reliability while on the other hand a smaller bubble denotes higher reliability. Figure 5.3 shows that the item difficulty probability measures are widely spaced and have bubbles of almost of the same size implying that the instrument contained test items which were both fairly easy and fairly difficult but fairly represented in the instrument. The even distribution of test items further indicates that they contribute equal in to the measurement of TSPCK. The bubbles were fairly small indicating high reliability of items in the test.

Thus, the Rasch scores have shown that the developed instrument is valid and reliable in measuring TSPCK of physical science teachers in electrochemistry. The high reliability indices places confidence and trustworthiness in the data collected using the developed TSPCK

instrument. Therefore, it can be employed on a large scale to measure quantitatively the quality of the topic specific PCK of physical science teachers in electrochemistry in other provinces in South Africa other than this sample with great confidence.

5.5 Concluding remarks

The main focus of this chapter was to indicate how the developed instrument was validated so to provide the answers to the research question 2. Firstly the adaptation and modification of the TSPCK rubric was discussed. The TSPCK rubric was found to be an effective scoring tool for the TSPCK instrument as well as a rating scheme for determining the quality of TSPCK. The developed TSPCK instrument underwent validation process with 21 practicing physical science teachers to determine its validity and reliability. I marked the teachers' responses with the approved TSPCK rubric first and then invited the independent peer raters to also mark the responses. This step was done to validate the scores and check the consistence of the scoring process. Our scores were compared and where there were disputes, scores were changed after a compelling argument was provided. Raw scores were peer validated by independent raters and agreement of 85% was observed. The raw scores from the TSPCK rubric were analysed by the Rasch model (MINISTEPS) which converts raw scores into probability scores of equal interval. The Rasch model summarises completely a person's standing on a variable, in this case, TSPCK. It is also used as evidence of construct validity of the diagnostic test as well as provide estimate of internal consistence of items. Here the persons and item reliability indices were determined as well as the rank or hierarchy of categories of TSPCK according to item difficulty.

On analysis of raw scores using the Rasch Model, the validity of the TSPCK construct was found to be acceptable with the conventional range of Fit statistics of -2 and +2. There was good overall fit of data. The internal consistency of test items as measured by Cronbach's alpha KR-20 is 0.84 implying that the instrument contains both easy and difficult test items. The value reflects high internal consistency of test items and this shows all

persons of different abilities were catered for. In addition, the person reliability index of 0.89 and an item reliability index of 0.97 were obtained.

The most difficult test items were on conceptual teaching strategy while least difficult test items were on learner prior knowledge. The item difficulty hierarchy order was a follows from the least to the most difficult: Learner Prior knowledge<Curricular Saliency<What is difficult or easy to teach<Representations/analogues/models<Conceptual Teaching Strategies.

In conclusion, the instrument showed a high degree of validity and reliability in measuring the quality of teachers' TSPCK on electrochemistry. The theoretical prediction agrees with the empirical prediction thereby indicating that the construct of TSPCK is valid, it exist as a separate construct from PCK. The person and item reliability indices were found to be acceptable as they were above 0.5. 0n calculating the Infit and Outfit statistics it was found that the construct was valid as the persons and items were found to be within -2 and +2. This implies that both the persons and the test items work together to measure the same construct-which is TSPCK in this case. Teachers' explanations did not show depth of TSPCK and hence the majority of participants demonstrated basic TSPCK. The teachers performed well in the learner prior knowledge category and poorly in the conceptual teaching strategy category as expected**.** The interpretive argument agrees with the calculated validity and this also gives further evidence of instrument validity. The order of item difficulty hierarchy is summarised as follows Conceptual Teaching Strategy**>**Representations**>**Curricular Saliency**>**What is easy or difficult to teach**>**Learner Prior knowledge components. This also indicates the validity of the developed TSPCK instrument because empirical evidence and theoretical arguments support the appropriateness of explanations and actions grounded on test scores (Messick, 1989).

The modified CK tool was also found to have acceptable values of validity as well as those of reliability. The internal consistency of the CK test items as measured by Cronbach's KR-20 value of 0.84 was obtained indicating a high degree of instrument reliability. This means that the instrument contained

test items that were both easier and difficulty and hence it can differentiate high achievers from low achievers.

5.6 Projection to the next chapter

The next chapter presents both quantitative and qualitative data analysis of findings on the large scale administration of the CK tool instrument to practicing physical science teachers.

Chapter 6

Capturing Content Knowledge

In the previous chapter, evidence of validity of the TSPCK achievement test was presented. The aim of this chapter is to present the results from the content knowledge test and hence offer answers to one of the research questions guiding study: research question 3. I begin by giving the concept or topics covered by the CK achievement test. I follow by analysing the task performance for those questions by highlighting difficulties on topics that appeared problematic. Furthermore, I deliberate on the relationship between TSPCK of teachers and their CK is deliberated. Lastly, a correlation statistical analysis and linear regression analysis of physical science teachers' topic specific PCK and their content knowledge is presented well.

6.1 Introduction

The chapter presents results of the CK achievement test in order to offer answers to one of the research questions guiding the study:

- What is the relationship of measured PCK of these physical science teachers and their content knowledge?

Content knowledge is a precursor of PCK (Rollnick *et al.*, 2008). So it is imperative to explore the content knowledge of the physical science teachers on electrochemistry and subsequently establish if there is a relationship between the measured TSPCK and CK (see section 1.4). The above question was answered in two parts:

1. What is the practicing physical science teachers' content knowledge about electrochemistry?
2. What is the relationship between topic specific PCK of these physical science teachers and their content knowledge?

To answer these sub-questions content knowledge of teachers was measured using a CK achievement test adapted from literature, modified and validated. Therefore, data collected using the content knowledge tool is analysed and presented in this chapter.

As in the previous chapter, data were collected from practising physical science teachers who are currently teaching grade 12 electrochemistry, in schools in Johannesburg. There was a cover sheet in the content knowledge tool that was used to capture teachers' demographic information (e.g. gender, current subject they are teaching, qualifications, subject majors, years of teaching experience and the number of years teaching electrochemistry). The content knowledge achievement test was used to collect information about the physical science teachers' CK in this study sample.

However, I should make it explicit that the data from the pilot study collected during different stages of construction of the content knowledge achievement test was not analysed. Data collected for the main test were analysed both quantitatively and qualitatively. The first part of the chapter presents descriptive statistics of data, followed by quantitative analysis then a correlation analysis of the relationship between the TSPCK and the content knowledge of physical science teachers and a regression analysis. A regression analysis is used to establish if there is a relationship between the measured qualities of TSPCK (see section 6.4) and their CK knowledge. A correlation analysis would determine the strength of such a relationship in the case it existed.

6.2 Content Knowledge of physical science teachers

On average, teachers in the study displayed considerably good content knowledge. The scores of the teachers out of 27 marks were converted to a percentage and are shown in Table 6.1 below.

Table 6.1: Physical science teachers' scores

Person	**CK Raw score out of 100**
MN01 (Lolo)	70.4
MN02 (Ben)	48.1
MN03 (Dola)	55.6
MN04 (Sammy)	70.4
MN05 (Sheena)	63.0
MN06 (Kashmiri)	96.3
MNO7 (Greg)	92.6
MN08 (Suku)	96.3
MN09 (Susan)	66.7
MN10 (Andy)	81.5
MN11 (Steve)	18.5
MN12 (Gugu)	96.3
MN13 (Edwin)	40.7
MN14(Tiane)	66.7
MN15 (Shelton)	26.0
MN16 (Vusi)	59.3
MN17 (Mbali)	77.8
MN18 (Leon)	85.2
MN19 (Frank)	81.5
MN20 (Xola)	77.8
MN21 (Shannon)	77.8
Mean SD	68.9 21.8

In general the nineteen physical science teachers have good CK as indicated by above average scores. A score of 50% was the critical acceptable score to indicate a good, sound of CK. Teachers who had scores below 50% were considered to have poor CK. The mean score of this sample of teachers was 68.9% marks (SD = 21.8), indicating a good mastery of the subject except for five teachers. The raw scores were subjected to the Rasch model to check how much we trust the scores. The Rasch scores of person measure confirmed this observation as the mean was 1.48 (SD = 1.55). However, 5 of the 21 teachers had the Rasch measures which were below 0 indicating a poor CK. This could be attributed by the fact that they had only taught electrochemistry in grade 10 and 11 and two teachers had indicated that they were currently teaching mathematics/mathematical Literacy. The other observation made was that these teachers were holders of either teaching certificates e.g. Secondary Education Diploma (SED) or Secondary Teachers Diploma (STD) or diplomas but had since either done a post graduate qualification or Advanced Certificate in Education (ACE)-an in-service teacher training course offered by universities. One teacher was a holder of National Diploma in chemical Engineering. What is interesting to note was the performance of participants MN14 (Tiane) and MN15 (Shelton), they are holders of the same teaching qualification (SED/STD) but their performance is quite different. MN14 (Tiane) demonstrated a sound content knowledge as compared to her counterpart MN15 (Shelton) (see Appendix A10 for demographic information). The two teachers scored 67% and 27% respectively in the CK achievement tests.

After subjecting raw scores the Rasch model, high values of person and reliability indices were obtained and are displayed in Table 6.2.

Table 6.2: Summary statistics for validity and reliability of CK tool

Reliability		Validity
Person reliability	0.78	All the Rasch measures fell within +2;-2
Item reliability	0.86	

Item measure mean set to zero & Units per Logit (log-odds unit) =1 for the entire test (UIMEAN=0 and USCALE =1)

All the Rasch measures fell within the +2 and -2 range of Infit and Outfit statistics thus indicating that the scores are valid. Also shown in Table 6.2 is that the person and item reliabilities were quite high indicating that the scores are reliable and trustworthy. This means that if the same test items are given to other similar sample it would yield the same results. The section that follows presents the results from analysis responses to the multiple choice of the content knowledge test.

6.2.1 Analysis of the Content Knowledge achievement test

The response combinations of the physical science teachers to each test item in the CK test are indicated in Table 6.3. The questions were grouped according to the concepts they are testing (see Table 4.3 for detailed grouping). Questions on the second row were concerned with electrode processes and half–cell reactions and their use in identifying spontaneity of reactions. Questions 7 and 11 tested the teachers' understanding of the concept of electrical neutrality in galvanic cells.

Table 6.3: Classification of teachers' responses towards the diagnostic CK test (N=21)

Test Item number	A(%responses)	B	C	D	E	No responses
1	4.7	4.7	*95	0	0	
14	9.5	*67	14	0	9.5	
4	5	5	0	*90	0	-
5	4.7	9.5	*71	10	0	4.5
6	0	0	0	*90	4.5	4.5
10	*71	19	0	0	0	9.5
15	0	*62	19	19	0	-
17	*71	9.5	0	19	4.7	-
20	14	*71	0	4.7	9.5	-
18	14	*81	9.5	9.5	0	-
19	4.7	4.7	0	*62	19	-
2	4.7	4.7	*91	0	0	
3	*76	4.5	14	0	0	4.7
8	9.5	*81	0	0	0	9.5
9	76	14	9.5	0	0	9.5
12	0	-	-	9	*76	4.7
13	0	4.7	-	24	*62	9.5
16	*81	14	9.5	4.7	0	-
21	*9.5	9.5		9.5	52	9.5
7	0	4.7	0	0	*95	4.7
11	24	24	*24	19	0	9.5

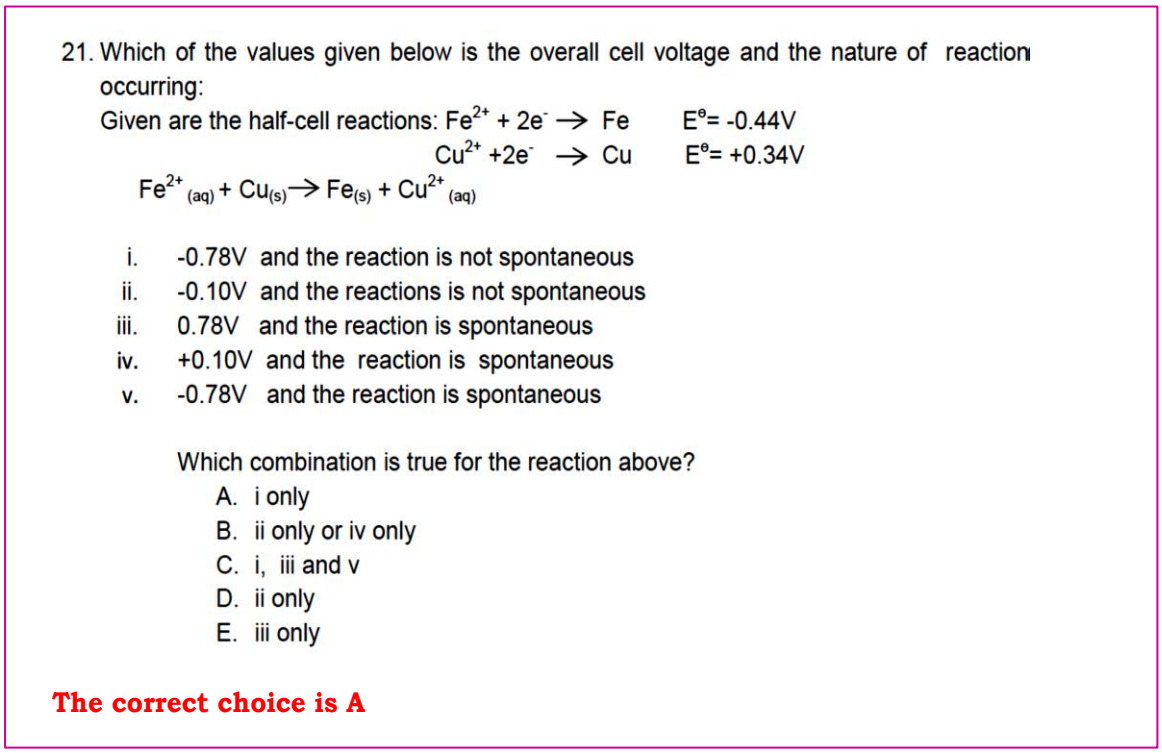
* indicate correct answer

Analysis of the physical science teachers' responses in the content knowledge diagnostic test indicated that almost all physical science teachers understand well the concepts of emf of the galvanic cell at equilibrium that it is equal to zero (see question 2, Appendix A5). Question 21 testing spontaneity of reactions proved to be the most difficult followed by question 11 which tested the teacher's understanding of the concept of charge distribution during maintenance of electrical neutrality in galvanic cells.

The discussions that follow in the sections below will centre on the following areas: conduction in the electrolyte, electrode processes, cell reactions including spontaneity and electrical neutrality in galvanic cells. Findings on topic areas which show a great concern as observed by most researchers in literature and as indicated by performance of learners in these specific areas (see report by the DBE, 2011, 2012) are presented and discussed below. The results of the study would be constantly compared with those obtained with those of the authors (Ogude & Bradley, 1994) to see if the misconceptions they found in High school students were still prevalent among practicing physical science teachers in my study.

6.2.1.1 Nature of reactions and cell potential of electrochemical cells

Question 21 tested the teachers' understanding of the nature of reactions taking place in a cell and is shown Fig. 6.1 below.



21. Which of the values given below is the overall cell voltage and the nature of reaction occurring:

Given are the half-cell reactions: $Fe^{2+} + 2e^- \rightarrow Fe$ $E^{\theta} = -0.44V$

$Cu^{2+} + 2e^- \rightarrow Cu$ $E^{\theta} = +0.34V$

$Fe^{2+}_{(aq)} + Cu_{(s)} \rightarrow Fe_{(s)} + Cu^{2+}_{(aq)}$

i. -0.78V and the reaction is not spontaneous
ii. -0.10V and the reactions is not spontaneous
iii. 0.78V and the reaction is spontaneous
iv. +0.10V and the reaction is spontaneous
v. -0.78V and the reaction is spontaneous

Which combination is true for the reaction above?

A. i only
B. ii only or iv only
C. i, iii and v
D. ii only
E. iii only

The correct choice is A

Figure 6.1: Sample of question 21 in the Final CK tool

For the analysis of questions related to nature of reactions taking place in electrochemical cells specifically, spontaneity and non-spontaneity, four physical science teachers identified the reaction with a negative overall cell

potential as non-spontaneous while 2 did not write their response at all in question 21. The rest of them (11) thought that the reaction was spontaneous although the E^{θ}_{cell} was negative. 11 out of 21 teachers still had difficulties in understanding which cell is spontaneous between the electrolytic and galvanic cell. It was further observed that 9 teachers could not tell if the reaction is spontaneous or not from the cell potential. 7 of the 21 physical science teachers failed to calculate cell potential and they still showed lack of understanding of the concept of the spontaneity of reactions. This implies that these teachers could have difficulties in teaching this concept to their learners.

Related to question 21 was question19 on characteristics of the electrolytic cells. This question further confirmed the fact that the physical science teachers in the study have difficulties in understanding which of the two cells- voltaic or electrolytic is spontaneous. Only 8 out of 21 teachers got the correct combination of characteristics, as the 33% of the teachers were attracted to alternatives A, B and E implying that the chemical reaction in the electrolytic cell is spontaneous. This line of thinking could be attributed by failure to understand the implications of negative or positive cell potentials on the type of reaction occurring in electrochemical cells.

In question 21, 13 teachers out of 21 did correct calculations of E^{θ} while the rest could not. The problems varied from computations to failure to identify the electrodes using half- cell reactions. This was also confirmed in question 20, in which 6 out of 21 teachers (29%) could not identify the substances that form at the cathode using half–cells. The other reason could be that these teachers might have failed to recall a known fact that a negative cell potential implies that the cell is spontaneous or vice versa.

Failure to identify the nature of reaction in question 21 could also have been attributed by difficulties in identifying the cathode and anode from half-cell reactions using the standard reduction potentials. This implies that s/he may not have sufficient content knowledge to teach this concept to the learners for conceptual understanding and this poor content knowledge

might as well impart negatively on the development of his/her PCK. The majority of teachers (90%) did well on questions 5, 6 testing their knowledge on electrolysis.

6.2.1.2 Using half-cell reactions to identify the electrodes

Identification of substances that form in the electrodes using half-cell reaction has also proved to be a difficult task for some teachers. This was evidence in question 17 and 20 respectively. In question 20, 6 teachers out of 21 (28%), failed to identify substances that form at the cathode of electrochemical cells from half-cell reactions. In question 17, the same number of teachers failed to identify the oxidising agents from a given reaction. Failure to understand electrode processes was a result of confusion on polarity of the electrodes which in turn affected the understanding conduction in the electrolyte. Despite the problems mentioned above, the teachers performed well as 72% got the correct responses in both questions.

Question 3 and 10 required the physical science teachers to choose a correct response from multiple choice options and then give an explanation for why the chosen option was correct. Question 3 was related to the factors affecting the cell potential. Below is the example of question and some of the responses obtained. For both questions (items 3 and 10), like in all question, multiple choice items a correct response was awarded a (1) and incorrect and no response (0) and the correct explanation was scored (2) and a partially correct response (1) and no response (0), this resulted in a maximum of 3 marks to be awarded to the question with a correct response with a correct explanation. In the partially correct response, the respondent gives an explanation which had a partially correct scientifically correct justification but with minor errors e.g. identifying factors correctly and failing to explain how each factor affects the concept in question. Table 6.4 below shows the teachers' responses obtained in the two questions.

Table 6.4: Classification of teachers' responses to questions 3 and 10 in the CK test (N=21).

Responses	Question 3	Question 10
Correct responses with correct explanations	6 (29%)	6 (29%)
Correct responses with partially correct explanations	1 (5%)	2 (9.5%)
Correct responses with wrong explanations	1 (5%)	2 (9.5%)
Correct responses with no explanations	8 (38%)	5 (23.8%)
Wrong responses	4 (14%)	3(14.2%)
No responses	1 (5%)	3 (14.2%)
Total	21(100%)	21 (100%)

Note: Main focus of the questions: Question 3 focused on factors affecting voltage of the cell; Question 10 focused on identification of electrodes with reasons.

From the Table 6.4 above, it is worth noting that the greatest number of physical science teachers in this study did not provide explanations as to why they chose a particular response for a particular concept although the majority had good subject matter knowledge. In question 3 which required the participants to identify the factors that do not affect the voltage of the cell, 76% of the physical science teachers mentioned that voltage of a cell is independent of the size of the cathode, however, they could not or did not explain why this is so whereas 4.8% of the physical science teachers did not give any response to this question at all. This clearly shows that most teachers had the knowledge of the subject matter whilst others could identify the concept but could not give explanation regarding to their choices. Moreover, the teachers that failed to respond indicate that they do not understand the cell potential; meaning that if presented with such a question to explain to the student, they would also fail to explain this concept. Here is question 3:

3. The voltage produced in the reaction $Cu_{(s)} \rightarrow Cu^{2+}_{(aq,0.1M)} + 2e^-$ is independent of:

Circle your choice:

A. The size of the cathode
B. The metal used for the anode
C. The temperature

Explain the reasons for your choice(s) above:

Figure 6.2: Example of Question 3 in the final CK tool

Here are some of the extracts from the teachers' responses (see Fig. 6.3) to show the degree how they engaged with the explanations to be classified as correct, partially correct and incorrect.

3. The voltage produced in the reaction $Cu_{(s)} \rightarrow Cu^{2+}_{(aq,0.1M)} + 2e^-$ is independent of:

Circle your choice:

(A) The size of the cathode
B. The metal used for the anode
C. The temperature

Explain the reasons for your choice(s) above:
i) Temperature change affects voltage due to its effect on rate of reaction. (ii) The metal used for the anode has a potential (electrode), its difference with that of Cu affects the voltage.

Suku* (MN08)'s response

The teacher chose a correct response with a correct justification. In this case, the teacher has good mastery of the subject matter knowledge.

3. The voltage produced in the reaction $Cu_{(s)} \rightarrow Cu^{2+}_{(aq,0.1M)} + 2e^-$ is independent of:

Circle your choice:

(A) The size of the cathode
B. The metal used for the anode
C. The temperature ×

Explain the reasons for your choice(s) above:

Temperature and concentration are stated conditions for electrochemical cells. The size of the cathode does not affect the voltage produced

Shannon (MN21)' s response

The teacher has correct choice and knows the conditions that affect the voltage of the cell but just states the conditions without giving an explanation as to how they affect voltage.

3. The voltage produced in the reaction $Cu_{(s)} \rightarrow Cu^{2+}_{(aq,0.1M)} + 2e^-$ is independent of:

Circle your choice:

A. The size of the cathode
B. The metal used for the anode
(C) The temperature

Explain the reasons for your choice(s) above:

The reaction is spontaneous chemical reaction and it is exothermic reaction.

Mbali (MN17)'s response

The teacher has a wrong response and a wrong explanation. The teacher could be having difficulty in comprehending the conditions on which the electrochemical cells operate and could not have understood the question itself.

*Pseudonyms are used

Figure 6.3: Sample of responses to question 3 in the CK

Sammy (MN04) and Mbali (MN17) show lack of understanding of the question itself. In addition, Sammy could not understand how the temperature affects the rate of the reactions as well as the voltage of the cell.

Question 10 sought the participants' understanding of the electrode processes. This was a continuation of question 8 and 9 in which the physical science teachers were to identify the positive and negative electrodes from a given diagram and then explain with a reason in which electrode oxidation take place. The physical science teachers in this case were expected to have an ability to identify from the direction the electrode where oxidation takes place by just mere looking at the direction of electrons. Fig. 6.4 show question 10 from the final TSPCK.

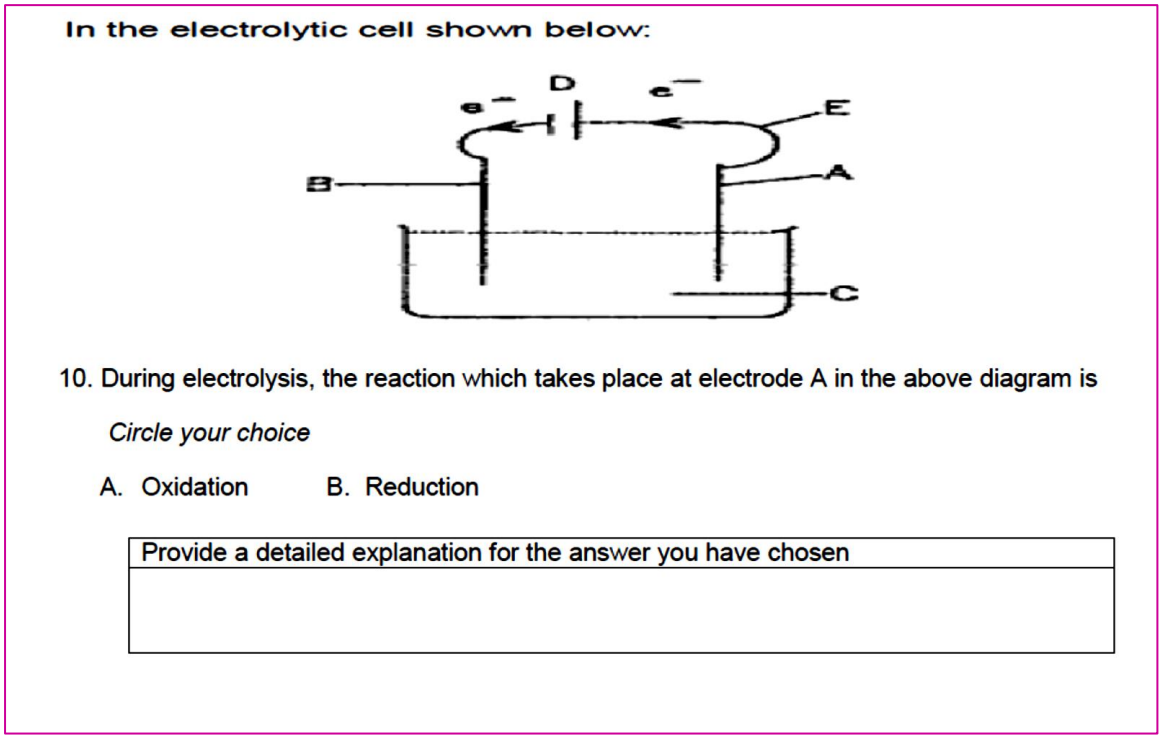
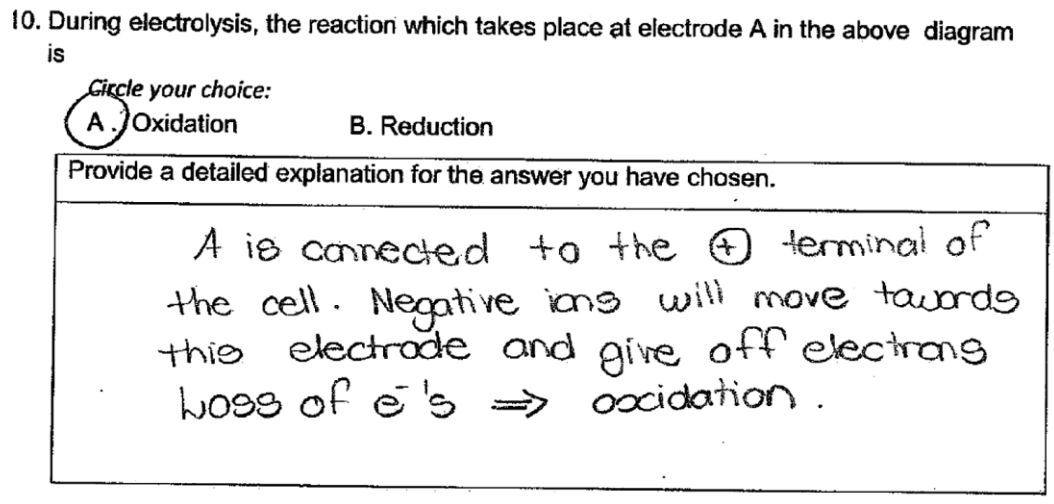


Figure 6.4: Example of question 10 in final CK tool

Identification of a positive and negative electrodes of an electrolytic cell proved to be very easy as over 75% managed to do that in question 8 and 9. It was pleasing to note that 71% teachers identified correctly the electrode where oxidation takes place. The challenge noted was on explaining their choices. Only 6 out of 21 physical science teachers (29%) answered both correctly, and gave a correct explanation that oxidation takes place in the

positive electrode in the electrolytic cell meaning that there is a loss of electrons which then move through the external wire to the negative electrode (loss indicated by direction). Another 2 physical science teachers pointed out that oxidation occurs in the positive electrode but they did not give a correct justification or had partially correct scientifically correct justification but with minor errors. Moreover, two physical science teachers gave the correct answer, but provided an incorrect explanation. Only four student teachers had a misconception that the electrode on the right hand side is always the anode (Boujaoude, 1991). Here, these teachers seemed to neglect the direction of electrons as the key for identifying the electrode where oxidation occurs. (See also Johnson 2000b). Additionally, 7 of the 21 physical science teachers gave a correct answer but no justification as to why they considered oxidations take place in such an electrode. About 14% of the participants gave a wrong response as they indicated that in the positive electrode reduction takes place. This error in judgment could be attributed by lack of understanding of cell construction itself. Fig. 6.5 show extracts from teachers' responses to illustrate the above observations.


10. During electrolysis, the reaction which takes place at electrode A in the above diagram is

Circle your choice:

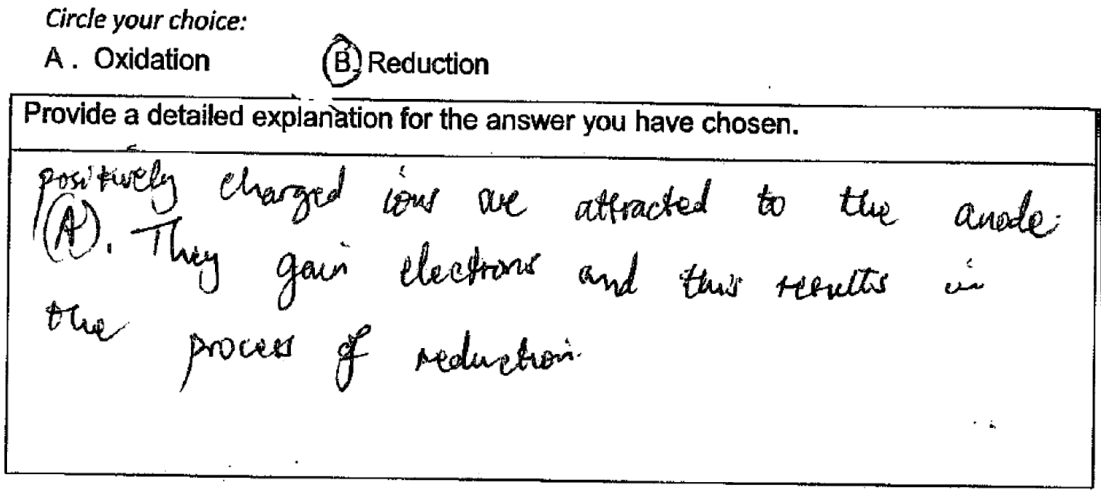
(A.) Oxidation B. Reduction

Provide a detailed explanation for the answer you have chosen.

A is connected to the ⊕ terminal of the cell. Negative ions will move towards this electrode and give off electrons loss of e⁻'s ⇒ oxidation.

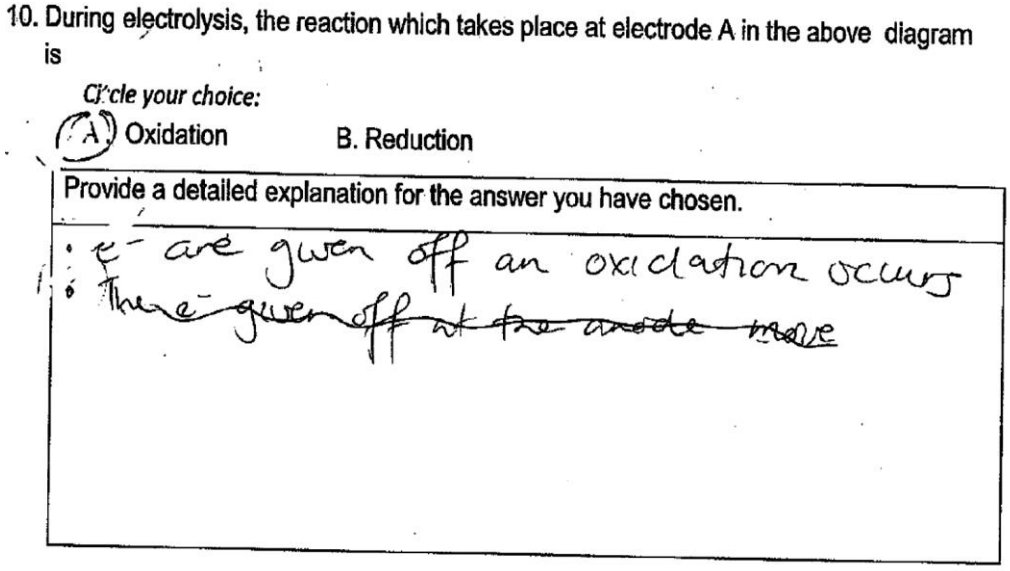
Kashmiri (MN06)'s response

The teacher has a correct choice and a correct justification. The teacher seems to understand the electrode processes and differences in electrodes in the two electrochemical cells



Sammy (MN04)'s response

The teacher seems to understand concept of reduction but fail to distinguish between the positive and negative electrodes in electrolytic and voltaic cells or the teacher may have failed to understand the question itself.



Shannon (MN21)'s response

The teacher gave a correct response and just gave a definition of oxidation with no further engagement with the question as to how oxidation occurs in the diagram.

10. During electrolysis, the reaction which takes place at electrode A in the above diagram is

Circle your choice:

A. Oxidation (B) Reduction

Provide a detailed explanation for the answer you have chosen.

B is the cathode: At the cathode, reduction ALWAYS occurs which is the gain of electrons i.e $X^+ + e \longrightarrow X$

↑ electron from cathode (-ve electrode)

Frank (MN19)' s response

The teacher chose a wrong response but a correct explanation of what reduction is and where it occurs. This teacher might have failed to identify the positive and negative electrode from the diagram and hence contributing to this wrong choice or the teacher has confusion on polarity of electrodes in galvanic and electrolytic cells.

Figure 6.5: Sample of responses of teachers to question 10

This difficulty in understanding of electrode processes by some physical science teachers and identification of electrodes from half-cell reactions was also supported by Question 17 and 20 respectively. Identification of substances that form in the electrodes using half-cell reaction has proved to be a difficult task to some teachers. This was evidence in question 17 and 20 respectively. In question 20, 8 teachers out of 21 failed to identify substances that form at the cathode from half- cell reactions. In question 17, only 11 physical science teachers chose the correct response of products of the cathodes from the given half reactions.

From the above given response, it can be concluded that some teachers still do not understand the conditions in which the electrochemical cells operate and therefore they would still fail to identify the errors made by their learners in this concept. As can be understood, most physical teachers could not explain why oxidation takes place at the anode during electrolysis

although they identified the electrode correctly in question 9. Four teachers gave a wrong response as attributed by their failure to identify the positive electrode from a given diagram in question 9 and two teachers did not respond at all. What is really striking in question 9 and 10 was the fact that those teachers who could not identify electrodes properly had also problems in understanding the electrode processes hence implying a poor CK on these concepts.

6.2.1.3 Electrical neutrality

Question 11 tested the physical science teachers' understanding of the concept of electrical neutrality. The concept of electrical neutrality is a problem to most teachers as most are not certain of how charge is distributed in an electrolyte. The physical science teachers seem to lack understanding on how electrical neutrality is maintained in the galvanic cell as shown by their failure to identify the charges on the electrolyte as the reaction proceeds in the galvanic cell. As a result the performance of physical science teachers was poor with 72% of the teachers giving scattered responses throughout all alternatives indicating 50-50 uncertainty and only 2 did not respond at all. Only 5 out of 21 physical science teachers (28%) chose a correct diagram depicting the concept of electrical neutrality properly. The teachers disregarded the fact that the charges should be balanced at all times in the electrolyte. The 4 (19%) teachers who chose alternative E indicates the misconception that there are electrons in the electrolyte. This misconception was also observed by Ogude and Bradley (1994) who found that 29% first year students had a similar misconception. This was further confirmed in the TSPCK category of what is difficult to teach. The majority of teachers indicated that this concept was difficult for learners. These results were not different from those obtained from the 40 students in Ogude and Bradley (1994) who found that student did not understand the concept of electrical neutrality. Table 6.5 shows the teacher's responses on the sub-questions of 11.

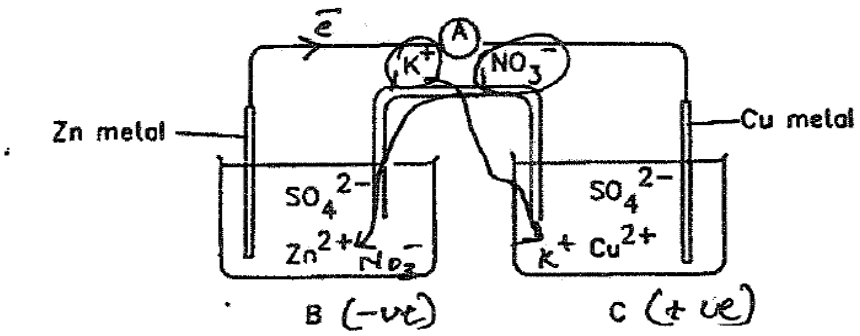
Table 6.5: Responses of teachers to question 11

Physical science teachers (N=21)			
	Correctly	Incorrectly indicated	Not indicated
Direction of electrons indicated	10 (48%)	1 (4%)	10 (48%)
Movement of all ions indicated	10 (48%)	11 (52%)	
Labelling of positive and negative electrodes	12 (55%)	5 (21%)	4 (19%)

Still on this same question, about 48% of teachers (about 10 out of 21) either did not respond to the questions that required them to indicate the direction of electrons, or movement of all ions on the diagram. In addition four of 21 physical science teachers did not label the positive and negative electrodes in the copper-zinc galvanic cell where as five gave wrong directions or labels (see Table 6.5). A similar observation was noted with labelling the direction of electrons. This implies that these physical science teachers do not understand the microscopic events taking place in electrochemical cells. This result is similar to Ogude and Bradley's study in 1994 in which they also found that in the same question, had a higher percentage (71%) of the 28 high school pupils and (72%) of the 40 first-year students showed wrong direction of movement of either electrons or ions or both. The remaining students did not respond to this question. However, this study differed from Ogude and Bradley's study in the sense that none of the physical science teachers in this study indicated electrons in solution. In their study, they observed that most students had doubts about directions of electrons and ions since 25% of the 28 high school pupils and 21% of the 40 first-year students showed electrons in solution. The physical science teachers could not have displayed this misconception on the diagram of the voltaic cell itself but the results revealed that there are still some teachers who still think that the electrons move in the electrolyte and ions in the wire as shown by their responses to question 4, 12 and 14 (see Table 6.3). 33% of the physical science teachers chose either options A, D or E in questions 14 that suggest that ions move through the wire, ions and electrons move

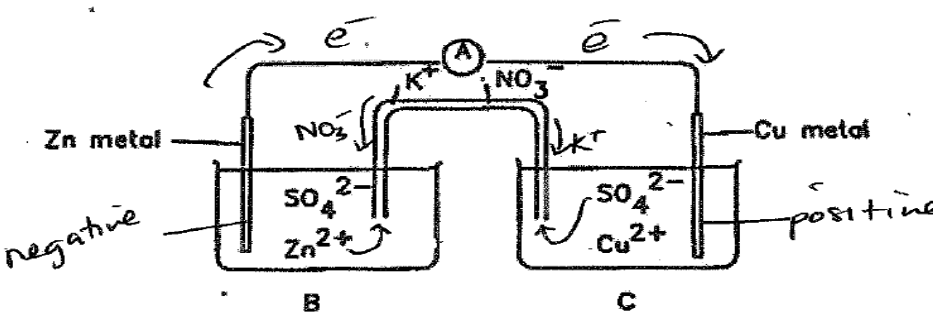
through the solution and ions move through the wire and electrons move in wire connected to cathode. Similar results but slightly higher, (57%) were obtained by Özkaya, Üce and Şahin (2003) in their study with 15 prospective chemistry teachers in Turkey. The teachers' responses are indicated in the Fig. 6.6 and Fig 6.7. Failure to understand the movement of electrons and ions might affect the subsequent teaching of the concept of electrical neutrality.

Below are examples of the responses given by some of the physical science teachers sample to the question 11 regarding to labelling of the electrodes as positive or negative and showing the direction of both electrons and movement of all ions.



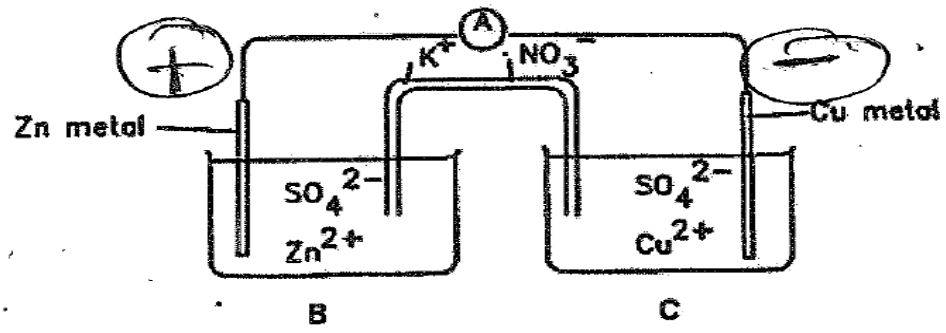
Frank (MN19)'s response

Frank correctly labelled the positive and negative electrodes and shown the movement of ions and electrons correctly. The teacher shows conceptual understanding of the electrodes in galvanic cell as well as maintenance of electrical neutrality.



Dola (MN03)'s response

The teacher shows a good understanding of the concept. The teacher identified all the movement of all ions and electrons as well as labelled the positive and negative.



Sammy (MN04)'s response

Sammy shows lack of conceptual understanding of the galvanic cell operation, the movement of electrons as well as ions in the galvanic cell. Teacher Sammy even labelled the electrodes wrongly. This teacher still holds the misconception that the anode is always on the left hand side and is positive and the cathode is negative. The teacher might be confusing the polarity of electrodes in electrolytic and galvanic cell. This observation is not surprising because teacher failed as well to identify the electrode where oxidation takes place in an electrolytic cell in question 10 (see section 6.2.2.3). The teacher might have failed to understand the demands of the question fully.

Figure 6.6: Sample of responses from some teachers to question 10 in Final TSPCK

Figure 6.6 indicate that some teachers have difficulties in presenting electrical neutrality diagrammatically. About 15 of the 21 of the teachers (72%) physical science teachers failed to identify the diagram that depicts electrical neutrality in question 11. If teachers themselves do not understand the concept of neutrality how then would they be able to explain it to the learners under their jurisdiction?

6.2.2.4 Redox reactions

Question 17 required the identification of an oxidising agent in the half-cell equation and 6 of the 21 physical science teachers (29%) could not identify the species that is oxidised or reduced from a given a half-cell reaction. Coupled with this question was question 10 and 13 and about the same number of teachers (29%) also exhibited uncertainty on where oxidation and reduction take place (see Table 6.4). These physical science teachers (6 out of 21) chose options that imply that oxidation and reduction occur in the electrolyte and the wire. These teachers had not considered the increase or decrease in oxidation numbers that occur when a species is either oxidised or reduced. This study shows that some physical science teachers themselves have problems in understanding redox reactions and using half-cell reactions to identify electrodes, and electrode products. Oxidising agent and oxidation seem to be still confusing to some teachers in this study sample. Failure to understand the oxidising or reducing agent makes it difficult to identify the anodic and cathodic products although. Nonetheless, question 5 was satisfactorily answered. For this reason, remedying teachers' misconceptions or difficulties would be worthwhile to prevent teacher-based errors or misconceptions. However, the majority of the physical science teachers showed that they understand Redox reactions, half-cell reactions. This means that they are not worried about their content knowledge when teaching this concept but could be worried about the knowledge of how to teach this concept for their learners to grasp it.

Despite these aforementioned misunderstandings/misconceptions the teachers general showed sound content knowledge. The following section presents correlation analysis and linear regression analysis to ascertain if there is a relationship between the measured quality of TSPCK and CK in order answer research question 3.

6.3 Quantitative analysis: Correlation analysis and Regression analysis

6.3.1 Correlation between TSPCK and Content Knowledge

The correlation between TSPCK and CK was ascertained using Pearson's product-moment correlation coefficient. The physical science teachers' scores on the content knowledge test were used as content knowledge while scores on the TSPCK test were used as TSPCK. A statistically significant relationship was established at $p<0.01$. This means that the probability of getting a correlation by chance is less than 1% (1 out of 100).

The correlation value lies between -1 and +1. The magnitude of the correlation coefficient value indicates the strength of the linear relationship whether it is positive or negative. Cohen, Manion and Morrison (2011) point out that the closer the value it is to -1 or +1; the stronger is the linear relationship between the two variables: in this case CK and TSPCK.
Creswell (2012, p.347) added that when a correlation value falls between range *0.66-0.85*, it implies that a good prediction can result from an independent variable to the dependable one. Furthermore, Creswell states that when a correlation range falls in the range *0.35-0.65*, their use is just for a limited prediction. The result of the correlation statistical analysis is shown in Table 6.6. The table shows that a statistically significant relationship existed between teachers' CK and TSPCK.

Table 6.6: Pearson product-moment correlation between teachers' CK knowledge and measured quality of TSPCK (N = 21)

Variable	*CK*	*TSPCK*
CK	1	
TSPCK	0.765	1

Note: significant at $p<0.01$

The product-moment correlation coefficient of TSPCK and CK was found to be ($r = 0.765$, $p<0.01$). This implies that there is a strong positive linear relationship between measured quality of PCK and the CK of teachers. The physical science teachers who performed well in the Content Knowledge

achievement test also performed well in the TSPCK achievement test and vice-versa. This relationship between subject matter knowledge and PCK (although not statistical founded but based on logic) was established by Rollnick and her colleagues in South Africa in 2008 in their case study of two teachers teaching the mole concept. For the teacher to answer PCK test items s/he must possess sufficient content knowledge. Mavhunga and Rollnick (2013) added that it is through this subject matter knowledge that a teacher is able to reason through the five components of TSPCK to make this knowledge accessible to learners. A graphical representation of the relationship between measured PCK of physical science teachers and their content knowledge is shown in Fig. 6.7 below.

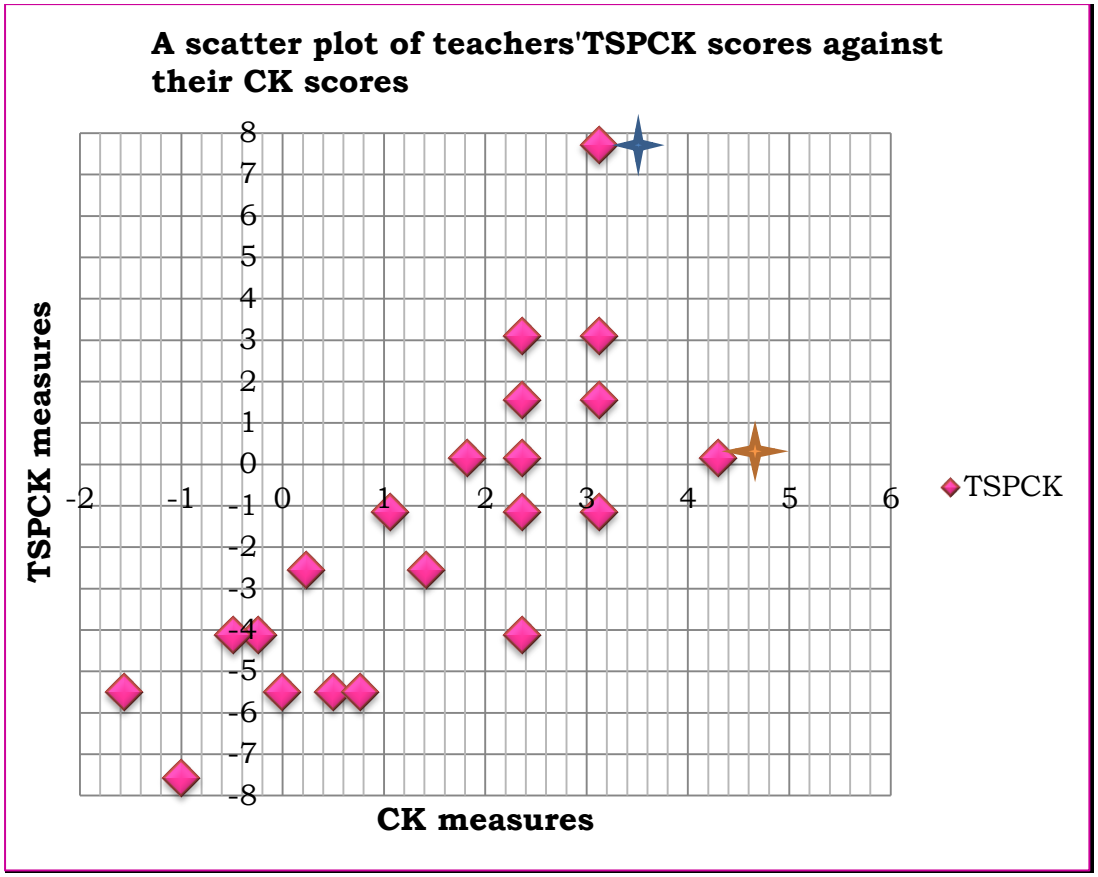


Figure 6.7: A scatter plot showing the relationship between teachers' TSPCK and CK.

On taking a closer look at the Rasch scores of teachers in the CK test vis-à-vis the Rasch scores on the TSPCK test it is worth noting that a high CK does not necessarily imply good quality PCK. Teachers marked with stars in Fig. 6.7 attests to this observation. It is not surprising that the teacher

marked with a blue star had a relatively low CK (compared to one with blue star) and a well-developed topic specific PCK. On the other hand, a teacher marked with an orange star had a considerable low topic specific PCK but with a high CK. This means that a teacher may fail to convert this content knowledge into a form that can be understood by the learners. This has been discussed in the previous chapter where we saw teachers with good content knowledge struggling in answering PCK test items under conceptual teaching strategies, representations, curricular saliency respectively. For example, Kashmiri (MN06) scored a very high in the CK achievement test (2.36) and got a satisfactory score in PCK achievement test of about 1.56. A high concentration of physical science teachers in the study had basic TSPCK although their CK is good as shown by their explanations that did not show depth of TSPCK. The overall TSPCK ratings of physical science teachers versus the amount of their CK are shown on a visual representation chart below. Although, Fig. 6.7 and 6.8 respectively are scatter plots of TSPCK scores vs. CK scores, the difference is that the latter shows the measured quality of TSCPK against the level of CK while the former shows the Rasch scores of teachers in the two tests. High CK/TSPCK means content knowledge that is above the mean (mean = 0) while low CK/TSPCK are measures below the mean.

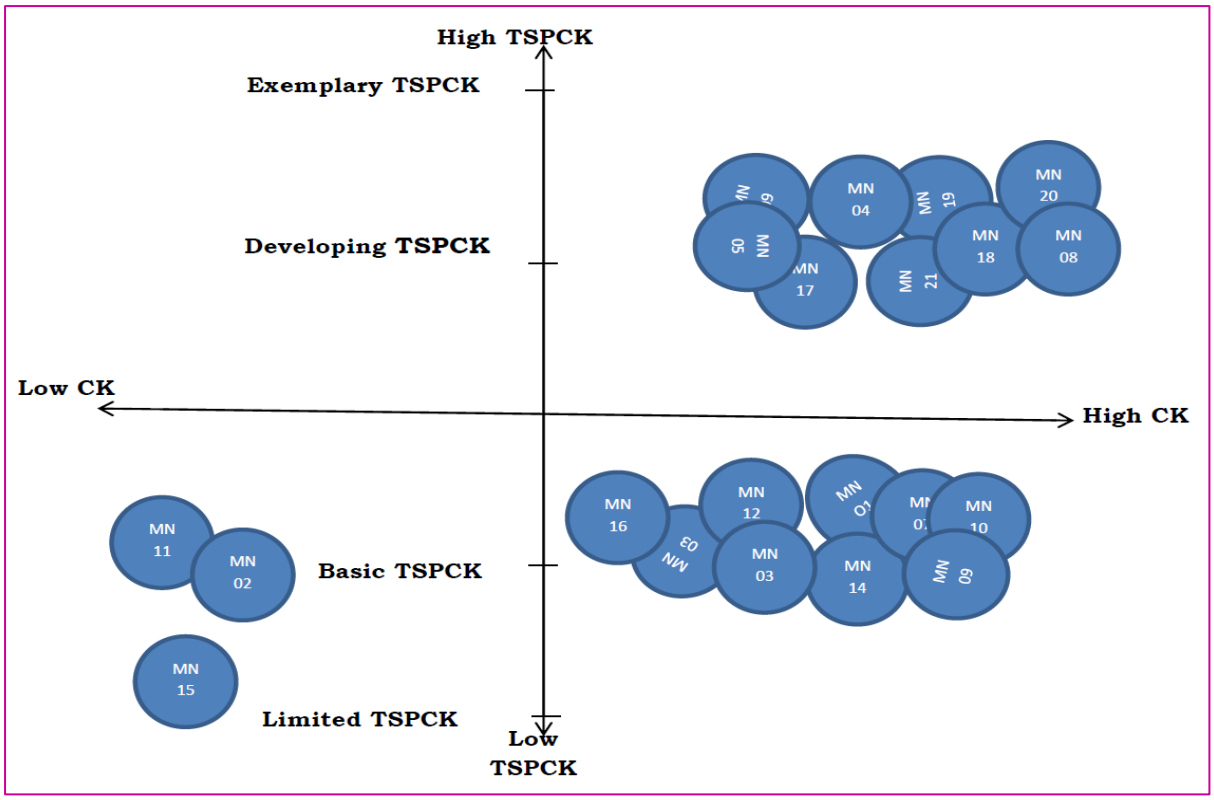


Figure 6.8: A visual representation of the relationship of the quality of TSPCK and the CK (not drawn to scale)

Figure 6.8 show that none of the teachers who had low CK had a well-developed TSPCK. This explains why we do not find persons in quadrant 2. The section that follows below presents and discusses the regression analysis results.

6.4 Linear regression analysis of physical science teachers' TSPCK and CK

A linear regression was carried out using ANOVA to confirm the results of correlation above. It was also used to estimate how the teacher's content knowledge (independent variable) predicts the teacher's PCK (dependable variable). Table 6.7 shows the result of linear regression analysis of physical science teachers' TSPCK and CK using ANOVA. R square is the coefficient of determination; it is the proportion of variation in topic specific PCK explained by teachers' content knowledge. Multiple R is the correlation between the observed and predicted values of physical science teachers' achievement in PCK test. Adjusted R is the amount of variance in the

depended variable (TSPCK) that was explained by independent variable (CK). For the goodness of fit of the model, significant F values should be less than 0.05. This implies that the deviations of the dependent variable (in this case TSPCK) are explained by the independent variable (in this case CK). Usually significance of the results obtained from the model is accepted if $p<0.05$ at 95% confidence level or if $p<0.01$ at 99% confidence level (if $p<0.01$) (Gupta, 2000; Gelman & Hill, 2007). Table 6.7 shows the result of linear regression analysis of teachers' CK and their measured TSPCK. The complete statistical summary is in Appendix A16.

Table 6.7: Model summary of linear regression analysis of teachers' CK and their TSPCK (N =21).

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.765
R Square	0.586[a]
Adjusted R Square	0.564
Standard Error	2.461
Observations	21

a. Predictor: (constant), CK.

The table shows that the value of R square is (0.586, $p<0.01$). This implies that 58.6% variation in physical science teachers' TSPCK scores is explained by the teacher's CK. This means that the remainder can be explained by other factors such as qualifications, experience, and length of training and contextual factors. Variance explained by test items is displayed in the scree plot in Appendix A15. The significant F values also attest to this observation as these values are less than 0.01: $p<5.27 \times 10^{-05}$ for CK and $p<1.74 \times 10^{-05}$ for intercept and thus indicating the goodness of fit of the model. Finding the amount of variance of TSPCK explained by qualifications, knowledge of learners and knowledge of context was beyond the scope of this research and hence it is an avenue that needs exploration. Also shown from Table 6.8 it is clear that physical science teachers with less teaching experience and a

corresponding fewer number of years of teaching electrochemistry had a proportionally low quality of TSPCK and vice versa. In each situation a sound content knowledge is required in order to answer the TSPCK test items as they require reasoning through the 5 knowledge components of TSPCK. In chapter 5, we saw teachers struggling to reason through the Conceptual Teaching Strategy component as well as in representation component. Research has shown that content knowledge is a precursor of PCK in addition to teaching experience. The above responses could lead to a conclusion that these teachers may have poor quality PCK. This indirectly means that these teachers may not be exposing learners to strategies that promote conceptual understanding or deep thinking.

6.5 Conclusion summary

In conclusion, the analysis of the physical science teachers` responses in the content knowledge diagnostic test indicated that all physical science teachers understand well the concepts of emf of the galvanic cell at equilibrium that it is equal to zero. Moreover, nineteen physical science teachers general indicated that they have good content knowledge as indicated by the above average scores-mean = 68.9% (SD = 21.78). Most teachers were within one standard deviation implying that they have good command of the subject matter and hence should be able to identify errors in their learners' responses or misconceptions as wells as errors in impressions on the textbooks. For the teachers to identify errors or misconceptions, s/he should rely heavily on the knowledge or understanding of the subject matter which therefore in turn influences his/her choice of pedagogical strategies. However, some physical science teachers in this study indicated a wide spread uncertainty in some of the topics such as electrical neutrality, spontaneity of electrolytic cells, electrode processes and where Redox reactions actual take place. The results show that these teachers could not explain this concept well to learners for conceptual understanding and therefore, resulting in poor performance by grade 12 learners in questions related to electrical neutrality in public

examinations. The learners usually inherit errors or misconceptions from their teachers.

In order to provide answers to research question 3, a correlation and a regression analysis was carried out. A statistically significant linear relationship between the measured physical science teachers' PCK and their content knowledge was established at 95% confidence level. The correlation coefficient of TSPCK and CK was (0.768, $p < 0.05$). This shows that there is a strong positive association between TSPCK and CK. This means that content knowledge is a prerequisite in answering PCK test items and also in the development of PCK. The R square value (0.586, $p< 0.01$) from linear regression analysis further confirms this fact and it shows that the 58% of observed variation in teachers' TSPCK is accounted for or predicted by the teachers' CK. The remainder could be explained by other factors such as experience, qualifications, years of teaching the subject etc. However, the study also established a statistically significant relationship between TSPCK and the years of experience and the number of years in teaching the subject (though it was not major aim of the study). This implies second to CK, there is a statistically significant relationship between the measured qualities of physical science teachers' TSPCK and their teaching experience.

6.6 Projection to the next chapter

In the next chapter findings are discussed, implications of the results as well as conclusions. The following chapter also tries to relate the findings to literature.

Chapter 7

Discussion of findings, implication of results and conclusions

This chapter gives a brief summary of how the study was carried out and also discusses the findings in relation to the research question for this study. Related literature is reviewed and implications of the findings presented. Conclusions, recommendations and limitations of the study are discussed lastly.

7.1 Introduction

The low pass percentage on questions involving electrochemistry in matriculation examinations was the main motivation which led to the undertaking of this study. I made this observation as a marker of grade 12 public examinations and also the reports by the Department of Basic education (2011, 2012) attest to this observation. Electrochemistry is regarded as a difficult topic to teach and comprehend for teachers, student teachers learn as well as learners (students) because of its abstract nature (Ogude & Bradley, 1996; Sanger & Greenbowe, 1997) and recently by Nester et al. (2008). For this reason, learners tend to perform poorly in this topic and literature indicates that the learners (students) in different countries hold a gross number of misconceptions about the topic in different countries including South Africa (see section 2.5). It has further been established that teachers are a potential source of these misconceptions in addition to those which learners bring into classroom from their social environment and from textbooks. Çalik & Ayas (2005) argue that if practicing teachers or student teachers do not fully hold refined subject matter knowledge and believe their existing conceptions are correct, they may propagate students' misconceptions. This suggested the need to establish how physical science teachers handle this topic and unpack their content knowledge so that it is accessible to their learners. In order to achieve this, an instrument was needed to measure physical science teachers PCK as well their content knowledge on this topic. As the focus was on a specific topic, a topic specific

approach to PCK was called for (van Driel *et al.,* 1999). For this reason, a Topic Specific PCK theoretical construct (TSPCK) guided the study and recalling as discussed in section 2.4, it is composed of 5 components namely: (i) Learner Prior knowledge, (ii) Curricular Saliency, (iii) What is easy or difficult to teach, (iv) Representations including analogies, and (v) Conceptual Teaching Strategies. It is believed that it is through these 5 content specific components of TSPCK from which transformation of content knowledge emerges (Mavhunga and Rollnick, 2013).

On taking a scan of available instruments none met the criterion of TSPCK construct and hence were not suitable to measure the qualities of TSPCK of physical science teachers in South Africa. The existing instruments are limited, since their focus is on (i) one or two knowledge components, (ii) not on practicing physical science teachers (see section 2.3.3) and (ii) not on electrochemistry. Those which are there focus on either learners or pre-service teachers in other subjects or chemistry topics. The need for a TSPCK instrument on electrochemistry was the rationale behind this study. This necessitated the development of a topic specific PCK instrument to measure the quality of PCK of the practicing physical science teachers in electrochemistry. This study served two purposes: to develop and validate a TSPCK instrument and to add to literature on topic specific instruments.

7.2 Reflections on the study

Construction of topic specific PCK test items was a challenging task since I had no experience in instrument design. Initially, I could not distinguish between CK related tasks and TSPCK related tasks and hence my ideas were muddled. Another difficulty was the fact that TSPCK test items were created from contextualised teacher tasks and no study in electrochemistry of this nature had been previously undertaken. Furthermore, I focussed on decontextualized misconceptions on electrochemistry and neglecting misunderstanding of concepts or errors that could cloud the teachers' understanding of electrochemistry.

I realised that it was extremely difficult to write TSPCK test items if I had little understanding of the topic itself. The TSPCK test items were to be aligned with the five components of the TSPCK theoretical construct (see section 2.4 for details) which guided the design of this unique instrument. This required correct content knowledge as well as alignment to the five components of TSPCK. I then realised why the reference team constantly picked up content rather than PCK questions in my first draft test items and this was a reflection of my lack of understanding of what TSPCK items (see Appendix A1). I recall one of the comments from the reference team which was: *'You don't have to write content items because there is a CK test that will take care of CK'*. As I proceeded with writing of the second draft of items then third I then found it much easier as I now could distinguish between the CK and TSPCK test related items. For example, designing test items that were under representations and Conceptual Teaching Strategies components was the most difficult. I acknowledge the tireless efforts of my two supervisors-chemistry experts in science education who had picked up certain electrochemistry issues in literature and during their supervision. We then picked up and included the model by Huddle *et al.* (2000) under representations in addition to diagrams of electrochemical cells commonly found in grade 12 chemistry papers. A question under conceptual teaching strategies was picked up from the study by Pitjeng and Rollnick (2012) on chloralkali topic. This solved my dilemma.

The strength of this study is that a unique instrument to measure TSPCK on electrochemistry was developed and it was found statistically to be valid and reliable. The power of this TSPCK tool lies in the fact that it was created from authentic responses from chemistry teachers obtained during piloting the draft tool with practicing teachers with many years of teaching electrochemistry at grade 12. The instrument was piloted more than once. The teachers' comments, their verbatim together with the comments from reference team of experts helped to refine the tool. The additional strength of this tool was that it was left semi-closed to solicit more comments from the

respondents. The teachers were to add more comments as it had built-in spaces.

If I was to do the study again I would pilot the draft tool with subject advisers, chemistry lecturers so as to get their authentic comments as well as they are involved in teacher education directly or indirectly. The major constraint was in the validation of final instrument. I could only reach a few teachers (21) due to time and financial constraints and this made my sample size small. For this reason the results could not be sufficiently generalised. The tool was targeting teachers who had taught electrochemistry for 5 years or more in grade 12 the grade where electrochemistry is examined. Since South Africa has a shortage of science teachers, getting these teachers was a problem. Thanks to the physical science honours class, I approached during their lecture the validation process was a little bit easier. Some practicing teachers were reluctant to write the test as they needed an incentive. If I had to repeat the study I would do the following changes:

(i) In the pilot study: I would pilot the draft tool with more than 5 teachers preferably teaching in different contexts and provinces to get authentic responses.

(ii) Sampling teachers for validation: I would sample the teachers from more than one province so as to confirm validity and reliability of the developed TSPCK instrument in different environments. In order to get a large sample, teachers should be approached in workshops and be requested to complete these so as to get a fairly large sample.

The use of MM allowed me to understand better the topic specific nature of PCK. The data was analysed both qualitatively and quantitatively in each stage of instrument development to the final analysis of the data collected. The use of the Rasch statistical package helped to establish the validity and reliability of the instrument. The Rasch model gave the reliability indices of

both the persons taking the test and the items. It also provided the internal consistency of the test as measured by Cronbach's KR-20 Alpha.

7.3 Summary

The study was set out to design and validate an instrument that could be used to measure topic specific PCK of physical science teachers. The study also sought to measure the quality of PCK of the physical science teachers using the developed TSPCK instrument and also the content knowledge of these teachers using a CK test adapted from literature. In addition, the study also aimed at exploring if there was a relationship between measured quality of physical science teachers topic specific PCK and their content knowledge.

7.3.1 Methodology used in this study

The study was conducted using Mixed Methods (MM) to address the research problems of the study and give answers to the research questions. MM was used because the design of the tool required both narrative (qualitative) and numeric (quantitative) approaches in the various steps towards its creation (Teddlie & Tashakkori, 2009) while still maintaining the pragmatist philosophical orientation. This research can be described as methodological in the sense that emphasis was on the process followed and subsequently the validity of the TSPCK tool on electrochemistry. MM was employed to analyse data. MM helped me to understand the relationship between TSPCK and CK better as well as the topic specificity nature of PCK. Literature indicates that mixed methods provide accurate and increased levels of confidence in research findings (Kellie, 2001) as well producing new knowledge by combination of findings from different research approaches (Foss & Ellefsen, 2002).

The study employed two data collecting instruments-the designed TSPCK instrument and the content knowledge tool. Data about practicing physical science teachers content knowledge was collected using a diagnostic test on electrochemistry-the Content knowledge achievement test while the data on the quality of TSPCK was collected using the developed instrument-TSPCK

achievement test. The teachers' responses to the TSPCK instrument were marked using a TSPCK rubric whereas a memorandum was used to mark their responses to the CK instrument.

7.3.2 Topic specific PCK (TSPCK) instrument

Rigorous steps were followed in the design of this unique TSPCK instrument. This involved rigorous consultation with the science reference teams, piloting and adjusting the instrument as informed by the pilot study as a means of improving the validity of the TSPCK instrument. The designed TSPCK instrument was validated with 21 practicing physical science teachers to find out if it was valid in measuring the quality of TSPCK.

7.3.2.1 Validation of TSPCK instrument

Before validation of instrument, Kane (2006) suggested that the criteria or assumptions on which the instrument is to be evaluated against must be put forward so that the validator knows what to look for when validating. Messick (1989) added that construct validity requires both interpretive and validity arguments. These assumptions were laid down in interpretive arguments which provide the rational, assumptions and expectations (Kane, 2006). While on the other hand, the plausibility and coherence of interpretive argument is provided in validity argument (Kane, 2006, p. 23). The assumptions were that TSPCK existed as a construct separate from generic PCK and has 5 components that are hierarchal in nature. The expectations were that the conceptual teaching strategies were the most difficult whereas the Learner prior knowledge is the least. Therefore, in this study, the Rasch model tested the validity argument i.e. if the theoretical assumptions in interpretive argument agree with empirical evidence. The Rasch model showed that both the items and the teachers' responses fell within the conventional accepted range of -2 and +2 for *Infit* and *Outfit* statistics (Bond & Fox 1991). The instrument measured what it was intended to measure. This implies both the items and persons worked coherently together to measure a single construct-topic specific PCK.

Data collected using the designed instrument was analysed in two parts: using quantitative methods- using the Rasch statistical package, secondly using qualitative methods by using task performance analysis using the responses given by the teacher on each component of TSPCK. On the other hand, data collected using CK test was analysed using descriptive statistics as well as quantitatively. The raw scores from the TSPCK rubric were peer validated and an over 80% agreement was achieved. Data was then analysed with the Rasch statistical model. Teachers' answers were also analysed qualitatively to establish if a relationship existed between the quality of TSPCK of teachers as measured by the developed instrument and their content knowledge, data was analysed using a correlation analysis and linear regression analysis. Following below is a discussion of findings in relation to literature under each research question.

7.4 Discussions of findings

7.4.1 Research Question 1.

The first question was: How can a valid instrument be designed to measure topic specific PCK of physical science teachers in electrochemistry? As indicated in section 7.1, the available instruments could meet the criterion of TSPCK construct: - a theoretical framework guiding the design of the TSPCK instrument and hence unsuitable. Thus, it was important to design an instrument that was would measure the quality of TSPCK construct as it was the theoretical framework guiding this study. This instrument was to be in alignment with the components of TSPCK construct discussed in chapter 2. In order to achieve this I followed a rigorous method of construction in design of the instrument which is discussed in details in chapter 4. At each stage of instrument (i.e. from conceptualization to final instrument that was validated). I was in regular consultation with a reference team of science experts in chemistry education in order to ensure face validity, content validity and construct validity. The experts checked ambiguity, wording, content alignment with grade 12 national curriculum standards as well as alignment with topic specific PCK framework. I created the TSPCK instrument from teacher tasks created in educational contexts. I also used

authentic responses from chemistry teachers obtained during piloting the draft tool with practicing teachers with many years of teaching electrochemistry at grade 12. This was an earlier contribution towards the validity of the tool. The teachers' comments, their verbatim together with the comments from reference team of experts helped to refine the tool. The different versions of the draft TSPCK instrument is a testimony on how thorough the process followed in the design of the instrument was. The results show that it is possible to design a valid TSPCK instrument with relevant criteria.

7.4.2 Research question 2

The second research question was: How valid is the designed instrument in measuring the PCK of physical science teachers in Gauteng province? The results from the Rasch statistical analysis show that the instrument is valid in measuring the quality of topic specific PCK of the practicing physical science teachers on electrochemistry in Johannesburg schools in the Gauteng province, South Africa. Both the person responses to the test items (with the exception of one participant) and the test items fell within the fitness statistics range of -2 and +2 thus indicating that the developed instrument is valid. This means that both the persons and the test items worked coherently to measure a single construct-topic specific PCK and the quality of the tool. The instrument was also found to be effective and reliable in measuring TSPCK of these physical science teachers. If we recall the Rasch model provides two reliability estimates: one of persons taking the test and the one for the items contained in the test. The person and reliability indices were found to be acceptable and quite pleasing. The reliability index of 0.5 is usually the traditionally accepted value (Bond & Fox, 1991). The internal consistency of the instrument as measured by Cronbach's KR-20 alpha value was found to be statistically significant as well. This implies that the test was well balanced; it contained both difficult and easy items. This means that it was able to distinguish between teachers with low topic specific PCK from those with high topic specific PCK and

hence the instrument is dependable. Qualitative analysis teachers' responses in each of the five categories indicated that the teachers performed differently in the five categories with the majority performing very well in the Learner Prior knowledge component test items and poorly in the conceptual teaching strategy and representation components respectively. The Rasch model ranked the conceptual teaching strategies as the most difficult with learner prior knowledge as the least. This attest to the validity of the instrument and TSPCK construct when the empirical evidence agrees with theoretical prediction (interpretive argument).

7.4.3 Research question 3

The third research Question was: What is the relationship between the teachers' measured quality of PCK and their content knowledge? Basically, I answered this question in two parts: in the first part I found how much content knowledge was possessed by teacher in this sample and secondly, I established if a relationship existed between the teachers' CK and their measured TSPCK. I followed the order of questions to answer research question 3.

What is the CK of the physical science teachers in this study sample?

I used the Content Knowledge test adapted from existing literature and past grade 12 examination papers to capture the content knowledge of these teachers. The questions extracted from literature were assumed to be valid. Although out of context, I felt that I should also subject the raw scores of the CK test to the Rasch so as to convert them from ordinal to probability measures for easier comparison with TSPCK scores. The CK test still displayed high validity and reliability indices despite extracting questions from different sources. On further analysis of the teachers' TSPCK versus CK, it is worth noting that a high concentration of practicing Physical science teachers in the study possessed high/sufficient content knowledge (Mean = 68.9%, SD = 21.8) to teach the topic of electrochemistry though a proportionally high concentration of these teachers had low quality topic specific PCK. This basically means that a high content knowledge does not

necessarily imply good quality or exemplary PCK. The teachers tend to fail to convert this content knowledge into a form that can be understood by the learners. Their explanations showed lack of depth especially in the conceptual teaching strategy category. This confirms the remark by Bucat (2005) that there is absolutely a big difference in knowing about the topic (CK) and the knowledge of teaching that topic (PCK) in a manner that could promote conceptual understanding the topic to the learners. I align myself with Bucat's comment. By knowing the topic does not necessarily mean that you can teach it effectively.

The majority of teachers struggled with the concept of maintenance of electrical neutrality and calculations of electrode potentials. Their answers were scattered all over the response options as they failed to identify charge distributed in an electrolyte as the reaction proceeds. The results are similar to those of Ogude and Bradley (1994) study. The teachers also confirmed maintenance of electrical neutrality and calculations of electrode potentials as difficult to teach. This observation confirms the outcry by examiners that the teachers may not be teaching this topic very well as learners still exhibit a gross number of misconceptions (see section 2.5 and 2011-2012 DBE reports). This implies that these teachers may use rote learning and drilling as their teaching strategies when teaching this concept. These teachers might as well be perpetuating these misconceptions. The problem areas which teachers in this study sample showed deficiencies in CK are discussed in section 6.2.2.3-6.2.2.4. I recommend that the Department of Education should organise more in-service teacher workshops on these topics as to enhance the CK of these teachers.

Moreover, it was found that a strong positive, statistically significant relationship between the quality of topic specific PCK and their content knowledge was in existence. A correlation of (0.77, $p<0.01$) was obtained indicating that content knowledge and topic specific PCK are highly correlated. Consequently, there was a positive statistically confirmation that the variation in the qualities of TSPCK observed in these practicing teachers was attributed by their content knowledge. The relationship was statistically

significant at 99% confidence level. A regression analysis confirming this relationship is shown in Table 6.7. The study showed that 58% of topic specific PCK is predicted by CK or in other words the variation in observed qualities of TSPCK in physical science teachers is explained by their content knowledge. It is worth mentioning that the 21 teachers in the study were in possession of the similar qualifications and some had the same number of years of teaching experience and that of teaching the topic (see Appendix A9. These results are in line with the qualitative findings of Rollnick et al. (2008) and Davidowitz & Rollnick (2011) in chemistry; the quantitative findings of Borowski et al. (2011) in physics and more recently by Mavhunga (2012) in the topic of chemical equilibrium. All of these studies endorse that CK is a precursor of PCK. Various authors maintain that a good content knowledge gives a teacher a sense of security and confidence as they plan and teach the learners, which gives a firm foundation for a teacher to develop appropriate PCK (e.g. Gess-Newsome & Lederman, 1995; Childs & McNicholl, 2007). Smith and Neale (1989) added that a more coherent CK is necessary for an effective PCK- in this study TSPCK.

The results of this study indicate that there were differences between the measured qualities of topic specific PCK of practicing physical science teachers both qualitatively and quantitatively. The physical science teachers in this study held basic PCK on electrochemistry as their explanations lacked depth. The Rasch measure for the teachers was -1.37, indicating a relatively poor quality of PCK.

The teachers in possession of good content knowledge showed better conceptual understanding of the topic as it was apparent that they reason through the 5 component of TSCPK as they plan, deliver their lessons, assess and carefully decide on what to teach or not to at a particular time. From the results, it was clear that the teachers demonstrated limited PCK in the Conceptual Teaching Strategy and Representation components of TSPCK.

Most teachers struggled in answering the questions in those categories. Ogbonnaya (2007) argued that the knowledge of the subject matter possessed by the teacher influences his/her classroom practices or behaviour.

Conversely, the teachers with low content knowledge showed a Limited to Basic PCK in all the five components with the exception of Learner prior knowledge category which most teachers showed PCK that ranged from developing to exemplary. On learner prior knowledge component, the teachers showed great awareness of students' misconceptions and they tried to confront the misconceptions. On a closer analysis the reasons for this awareness was the teachers' experience as learners themselves and also in teaching the topic. The teachers had taught the topic for at least 5 years.

Similar to this finding, Mavhunga (2012) used a sample of 16 pre-service South African physical science teachers on the topic chemical equilibrium and showed that pre-service teachers found answering TSPCK test items under conceptual teaching strategies difficult. The results are different from those obtained on the topic of chemical reactions by Usak, Ozden and Eilks (2011) in Turkey who found that the 30 science student teachers had deficit in CK and had poor PCK as well as expected from beginning teachers. On PCK, Usak and colleagues had focused on 3 PCK components namely: knowledge about instructional strategies; knowledge about students' learning difficulties and knowledge about learning assessment.

7.5 Conclusions and implications

Recently, there has been a wide spread interest in measuring the quality of topic specific PCK of both the pre-service and practicing teachers (Davidowitz and Rollnick, 2011; Mavhunga and Rollnick, 2013; Aydeniz & Kirbulut, 2012). This emphasis on PCK is premised on the belief that a high level of PCK can make a considerable impact on the quality of teaching delivered by the teachers to learners and consequently on the quality of learning experience in most classroom environments (Grossman, 1990; Park *et al.,* 2011). Based on this assumption, we have seen researchers coming up with

a variety of ways in an attempt to measure the impact of PCK on the quality of teaching and learning. For example, Mansor, Halim and Osman (2011) in their study to investigate the impact of PCK on students' conceptual understanding of cellular respiration, attested that the learners' understanding of cellular respiration is influenced largely by teachers' PCK.

Quite a number of instruments to measure topic specific PCK in science teachers have been designed and are documented in literature. In an attempt to measure the levels of PCK of science teachers, the researchers in some studies asked teachers to design a lesson plan or teach a mini lesson on a specific topic or write CoRes and PaP-eRs (Loughran *et al.*, 2004, 2006, Rollnick, *et al.,* 2008). These methods of measuring sophistication of PCK had a shortcoming in that pre-service teachers could not make a lesson plan for each topic and also teach it due to time constraints.In recent studies, quantitative instruments were developed from teacher tasks, for instance in mathematics (Riese & Reinhold, 2009), in science (Park *et al.,* 2011) and in technology education (Rohaan *et al.*, 2009). Mavhunga and Rollnick (2013) have developed a tool to measure topic specific PCK of pre service teachers in chemical equilibrium in the South African context.

In electrochemistry, the studies to develop instruments to measure either the quality of generic PCK or topic specific PCK have just begun. The assumption is based on the fact that PCK is specific for specific topics (Veal & MaKinster, 2009). Secondly PCK promotes conceptual understanding of certain concepts/topics that are abstract and viewed as difficult to learn or teach

Another venture in Turkey, Aydeniz and Kirbulut (2012) developed a STSPCK instrument to assess pre-service science teachers' topic specific PCK of electrochemistry. In the above mentioned two Turkish studies, the concern was on prospective of pre-service teachers not on practicing teachers. In South Africa we have limited knowledge of any study that has developed an instrument of this nature to measure the quality of TSPCK for

both the pre-service and practicing teachers. So this was the dimension of my study. This study, therefore, had dual purposes which were to develop a valid instrument as well as adding to literature.

The study sought to develop a valid diagnostic TSPCK instrument that could be used to diagnose the quality topic specific PCK of physical science teachers in Johannesburg schools, Gauteng province in South Africa. The study revealed that it is possible to design such as instrument. This is a valuable contribution to the body of science education knowledge base. In addition, the study intended to explore the content knowledge on electrochemistry as well and then determine if a relationship existed between TSPCK and their CK. In literature, most two-tier multiple choice tests were used to diagnose students' misconceptions and a few of them measured the content knowledge of teachers e.g. The *ACER Teacher Education Mathematics Test* (TEMT) (ACER, 2004) tested the mathematical attainment of 426 beginning primary trainee teachers in Australia. Ryan and McCrae (2005/2006) in their study used the test to reveal errors, misconceptions and teaching strategies used by these mathematics pre-service teachers in order to provide diagnostic feedback. The chemical equilibrium achievement test (e.g. Mavhunga, 2012) measured the topic specific PCK of pre-service teachers and practicing teachers in chemical equilibrium. By knowing the teachers' content knowledge in the topic on electrochemistry, insights would be gained on whether it is lack of or poor subject matter knowledge or their teaching skills that contribute to low achievement of learners in grade 12 public examinations as alluded to in the previous section. The teachers may develop better teaching strategies or learn from experienced teachers if they find that their current methods are not sufficient in addressing learners' difficulties in electrochemistry.

Therefore, a developed TSPCK instrument TSPCK could be useful in the sense that it can be readily administered as its validity is now known. Also the findings suggests that the aforementioned instrument, has a potential to provide dependable information about the quality of topic specific PCK of

practicing teachers on electrochemistry as it has been statistically found to be valid and reliable. The findings of this study are similar to that of Aydeniz and Kirbulut (2012) who demonstrated that it is possible to develop a reliable instrument to measure topic specific PCK of pre service teachers in electrochemistry. Aydeniz and Kirbulut also found that their developed STSPCK instrument was reliable in measuring the TSPCK of the 31 Turkish pre-service science teachers. My study differs from that of Aydeniz and colleague in that my TSPCK instrument has 5 knowledge categories of TSPCK where as their STSPCK has only three categories namely: assessment, curriculum, and instruction. The developed TSPCK instrument might even give a prediction that if learners are taught by teachers with exemplary TSPCK and a corresponding more content knowledge than by teachers with limited TSPCK and less subject matter knowledge, they are likely to achieve better academically in the topic of electrochemistry. The content knowledge test also can give an indication of the amount of content knowledge possessed by the teachers on the topic of electrochemistry and help uncover their misconceptions.

In addition, the findings suggest that the developed TSPCK instrument might be used for teaching purposes so as to boost the practicing teachers' TSPCK on electrochemistry. Therefore, science education programmes or teacher intervention programs aimed at improving the teaching of electrochemistry may use it (TSPCK instrument) as a teaching tool. The teachers could answer the questions at their spare time. The practicing physical science teachers in the study showed that they have basic PCK in electrochemistry and this provide a clue why learners in grade 12 tend to perform poorly in the matriculation examination on this topic. This suggests that teachers may not be teaching this topic for conceptual understanding as shown by the limited PCK on the Conceptual Teaching Strategy component of PCK. This implies that these teachers may be resorting to algorithms and facts (Kind, 2009).

Moreover, the findings revealed that the practicing physical science teachers had sound content knowledge. The teacher content knowledge test could

potentially measure the content knowledge of these practising teachers and help to uncover their errors and misconceptions before they are passed on to their learners. The learners usually inherit errors or misconceptions from their teachers.

Since the other aim of the study was to establish if a relationship existed between the measured TSPCK of teachers and their CK, the findings further revealed that a statistical significant relationship existed. This implies that a teacher's manifestations in classrooms are a pointer of the kind of topic specific PCK they have and also what they know about the subject. Other factors such as experience in teaching the subject and beliefs, knowledge of learners and the context would come into play. Also established in this study (although out of context) was that there was a significant relationship between the measured qualities of TSPCK with the years of teaching. Research has shown that subject matter knowledge is a precursor of PCK in addition to teaching experience. Teachers with poor quality or limited TSPCK might not be exposing learners to strategies that promote conceptual understanding or deep thinking.

7.6 Recommendations

In light of the findings above, the following recommendations are made.

7.6.1 Large scale administration of TSPCK instrument to service teachers in and outside South Africa

The study recommends that the developed TSPCK instrument should be administered on a larger scale to other practicing teachers within the Gauteng Province and in other provinces in South Africa. Although the instrument was developed and validated within the South African context, the study further recommends that this instrument be applied to other teachers in other countries as well to establish teachers' baseline knowledge on teaching this topic since it was found to be valid and reliable. It is worth mentioning that the instrument has since been taken up by a further 65 practicing physical science teachers in different backgrounds and it has been used successfully.

7.6.2 Application of TSPCK instrument to pre-service teachers

The study further recommends that this instrument be used to enhance quality of topic specific PCK of pre-service teachers on electrochemistry. The quality of TSPCK of pre-service teachers was not measured due to time limitation and hence the study could be extended to pre-service teachers. The current study targeted teachers who have 5 years or more of teaching experience to test the validity and reliability of the instrument.

7.6.3 Incorporation of TSPCK instrument as a training tool in teacher workshops

Teacher intervention programmes or workshops on electrochemistry should not only concentrate on content knowledge only but as well on topic specific pedagogical strategies aimed at improving conceptual understanding of electrochemistry. The developed TSPCK instrument might be a valuable tool to be incorporated into these programmes or workshops so as to check the physical science teachers' ability to answer PCK test items or to reason among the components of TSPCK. We have seen in the study that high content knowledge does not necessarily imply that the teachers are able to handle the topic very well in classrooms. In short, the study revealed that though the teachers had good CK some of them had low PCK. These intervention programmes or workshop should as well focus on improving conceptual teaching strategies which have proved to be difficult for most of the teachers in this study.

7.7 Directions for future study

Application of the validated TSPCK instrument to measure TSPCK of practicing physical science teachers with less than five years of teaching and probably comparing their PCK with those with 5 years or more could be another avenue for exploration. The developed TSPCK instrument and the Content Knowledge tool could be used to measure the qualities of TSPCK and the content knowledge of pre-service teachers respectively before they leave their teacher training institutions. The CK tool might uncover their

misconceptions before leave these institutions and their tutors could possible remedy them. Future research should look into the applicability of the developed TSPCK instrument to other countries outside South Africa.

The study explored the relationship between the measured qualities of teachers' topic specific PCK and their content knowledge. Other future studies could involve investigating the relationship between:

i. The qualities of topic specific PCK of physical science teachers and their educational qualifications and years of training.
ii. The qualities of topic specific PCK of physical science teachers and teaching experience and years of teaching the topic.

7.8 Limitations of the study

The results of this study are not generalised due to the sample size which was not large enough and they are unique to the individuals who took part in the study as well as unique to the context where the teacher is working. Sampling of teachers was a problem as teachers from different teaching and learning context are targeted, therefore, financial resources and time was a limiting factor. More teachers could have been reached. Due to practical considerations the study was limited to practicing physical teachers in Johannesburg schools. Thus a large scale application might provide confirmation of the validity of this newly developed TSPCK instrument as well as its reliability.

7.8.1 Limitations of the TSPCK instrument

Despite, the high validity and reliability indices of the TSPCK instrument, the developed instrument had its own limitations. These were:

i. The test is long and it makes big demands on the teachers.
ii. I and the reference team may have picked on certain content which could not have been familiar to physical science teachers.
iii. Language used: Some of the language used may not have been familiar to everyday use by participants e.g. words like "concept" and main ideas. Participants could be using these interchangeably to mean the same thing. Thus participants were mixing big ideas and

subordinate ideas in their responses despite the fact that the word ‘main ideas’ was defined for them.

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Appendices

Appendix A1: Electrochemistry TSPCK Test First draft

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:

Answer all questions in the spaces provided.

Section A: Demographic information

Background information of participants

Name			
Gender	Female	Male	
Current subject taught:			Grade (s):-
Number of years of teaching Science			
Other subjects taught (Science and/ or maths)	Highest level taught (e.g. Gr 10)		Number of years teaching the grade:

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

CATEGORY A: LEARNERS' PRIOR KNOWLEDGE ON A GIVEN TOPIC

1. What comment would you write on a learner's script who writes:

Conduction through the cell is due to movement of free electrons attached to ions which are moving from ion to ion and from one electrode to another.

Write your comment in the space below.

2. Reflecting on your experience of teaching this topic (electrochemistry), what students misconceptions/or difficulties are associated with this topic have you noticed?

Write your answers in the spaces given below

3.0. What is the purpose of the salt bridge in galvanic cells? Explain.

Write your answer in the space below.

CATEGORY B: CURRICULUM SALIENCY

4.0. Questions 4.1 -7.0 relate to planning and sequencing of concepts.

4.1. What concepts in electrochemistry at Grade 12 do you believe are the most important for your students to understand by the end of the instruction of this topic? Why?

Write your answer in the space below.

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

6.0. What topics must have been covered in chemistry before you can teach electrochemical cells?

List of Topics to be taught before electrochemical cells	**Place them in a sequence** (the one to be taught first , place it as No. 1)	**Provide reasons for the proposed sequence**
	1.	
	2.	
	3.	
	4.	

7.0. How do you know whether your students understand a concept you teach or not?

Write your response in the space below.

8.0. How do you identify the element that has been oxidised in a chemical reaction?

9.0 What is the purpose of a salt bridge? Explain how electricity flows through the salt bridge?

10.0 Why is it important for learners to learn about electrochemistry? Identify reasons related to:

i. **Conceptual Progression**
ii. **Application**
iii. **Motivation**

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

11.0 What concepts do you expect students would have difficulties in electrochemistry? Explain why you consider the chosen topics difficult to teach.
Write your answer and your reason(s) in the table below.

Concept	*Why is it considered difficult to teach*

12.0 How do you know when your students have misconceptions/difficulties?
Write your answer in the space below.

CATEGORY D: REPRESENTATIONS/ANALOGIES/MODELS

13.0 What forms of representations do you use in teaching this topic e.g. graphs, equations, symbolic, sub micro and macroscopic representation?

Write your answer in the space below.

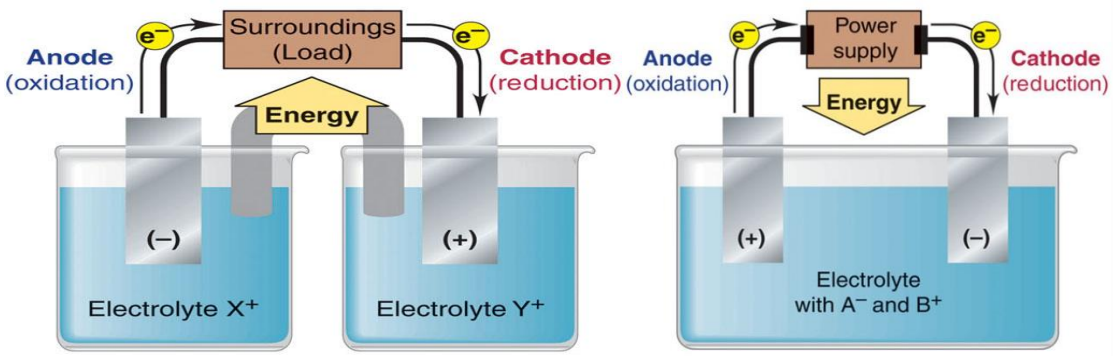
14.0 Why would you use these procedures?

Write your answer in the space below.

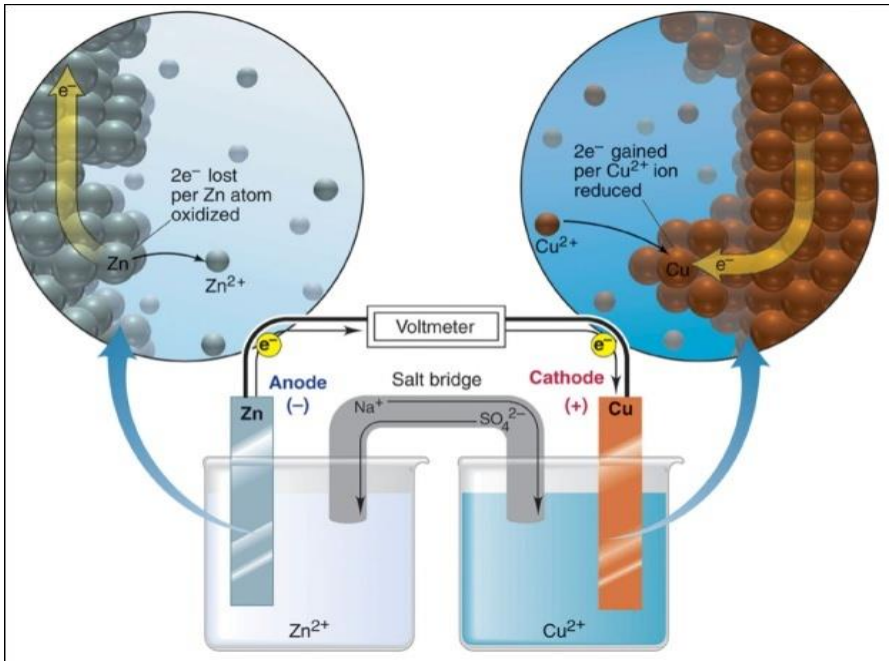
Electrochemical cells

15.0 Below are possible representations/analogies/models for teaching the concept of electrochemical cells (galvanic and electrolytic cells).

Representation 1



Representation 2



Representation 3

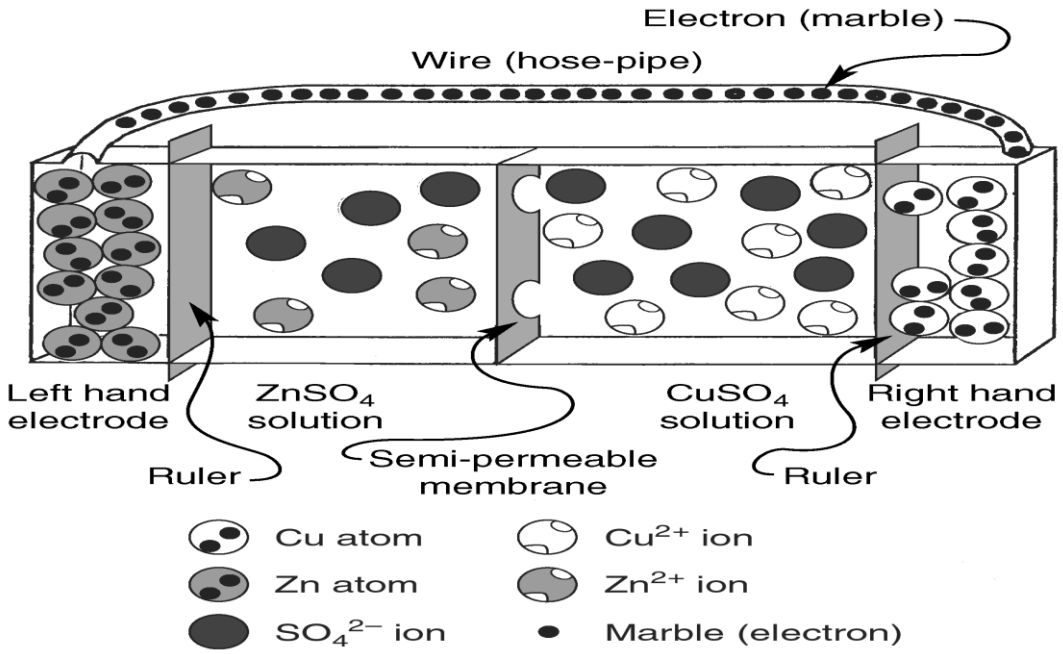
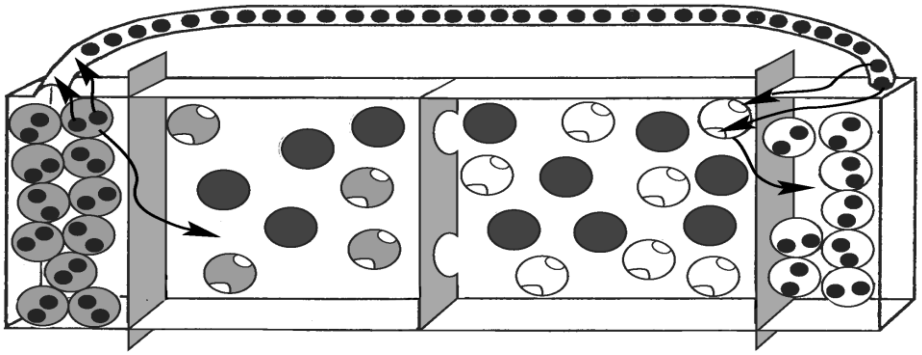
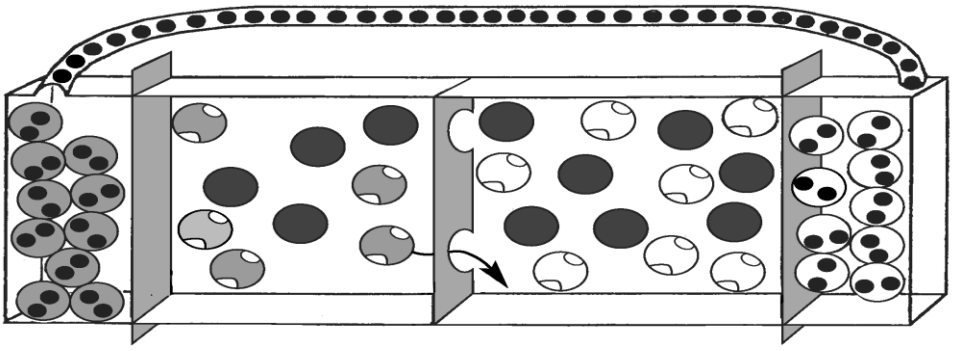


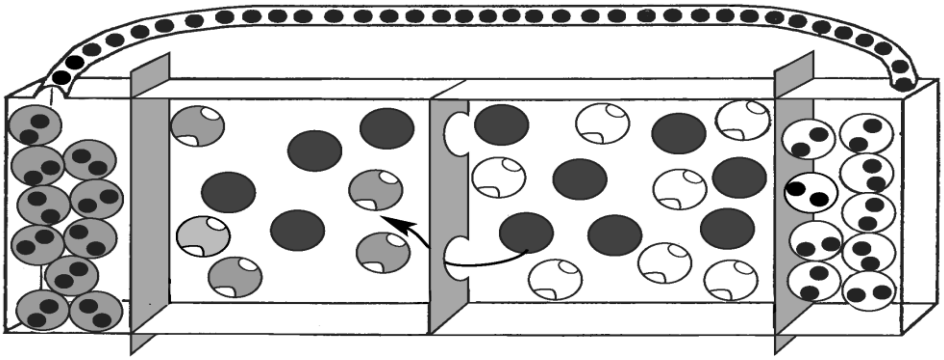
Figure 3: Concrete model for teaching electrochemistry.



a



b



c

Figure 2. The working of the electrochemistry model.

⟶ Directions of ions and electrons

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		

15.1. Which representation do you like most?

15.2 How would you use the representation that you like most?

CATEGORY E: TEACHING STRATEGIES.

16.0 What do you usually consider when you plan a lesson? (Learning difficulties specific to this topic, learners' background / prior knowledge of the topic/language etc.) Explain briefly the reason for such consideration

Write your answer in the spaces below

17.0 What specific strategies do you employ to enhance the understanding in this topic by the learners? How would you help learners' correct misconceptions/overcome difficulties you identified in this topic? Why would you use these procedures?

18.0 What strategies can you share about the teaching of this topic that you think have contributed to the success of your teaching this topic?

Write your answer in the spaces below

Appendix A2: The Topic Specific PCK test Draft 2

Electrochemistry TSPCK test

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

Kindly .complete the tables as comprehensive as possible

Section A: Demographic information

Background information of participants

Name			
Gender	Female	Male	
Current subject taught:			Grade (s):-
Number of years of teaching Science			
Other subjects taught (Science and/ or maths)	Highest level taught (e.g. Gr 10)		Number of years teaching the grade:

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 ☐ ☐

If yes, indicate how many years and how many classes in each year:

Grade(s)	Number of Years

Answer all questions in the spaces provided

Code:

CATEGORY A: LEARNERS' PRIOR KNOWLEDGE

1.0 How do you give feedback verbally to a learner who writes on a script:

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

Write you comment in the space below:

2.0 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?"

Write your answer in the space provided below:

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

Write your answers in the spaces given below:

CATEGORY B: CURRICULAR SALIENCY

4.0 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 ideas[1] for your students to understand by 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

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

Suggested concepts and sequence	Reasons for selection	Reasons for sequencing
1.		
2.		
3.		

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

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

5.0 What topics must have been covered in chemistry before you can teach electrochemistry?

List of Topics to be taught before electrochemical cells

6.0 Why is it important for learners to learn about electrochemistry? Identify reasons related to:

i. Conceptual Progression
ii. Application
iii. Motivation

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

7.0 What concepts do you find difficult to teach in electrochemistry? Select your choice and provide reason(s) in the table below. You may also add you own

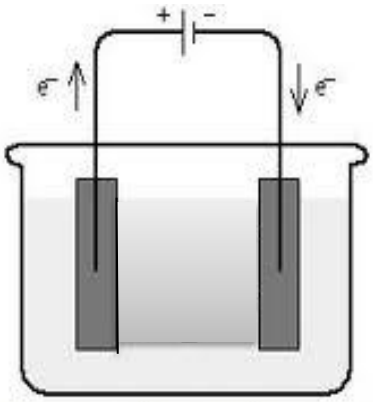
Concept	√	Why is it difficult to teach?
Cell construction Galvanic vs. electrolytic cells		
The calculation of cell potentials		
Identification of anode and cathode using $E^{\ominus}$ values/ Using half- cell reactions to identify the electrodes		
Conduction in the electrolyte		
Electrical neutrality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

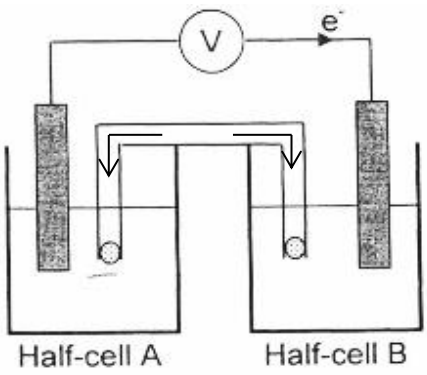
Respondents given a chance to give their input in the tool during instrument development to get authentic answers

CATEGORY D: REPRESENTATIONS/ANALOGIES/MODELS

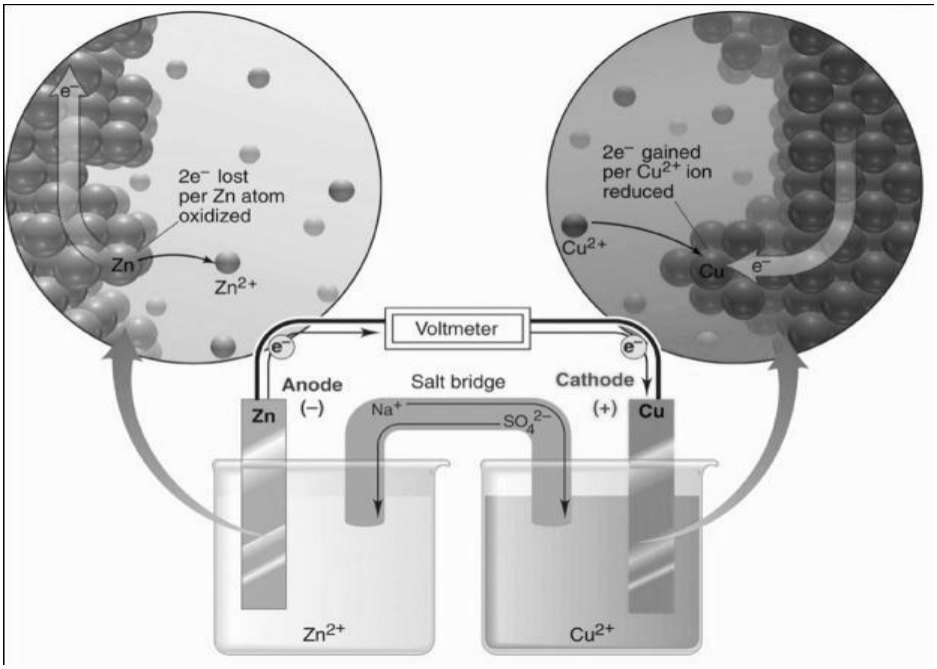
8.0. Below are possible representations/ for teaching the concept of electrochemical cells (galvanic and electrolytic cells).

Representation 1

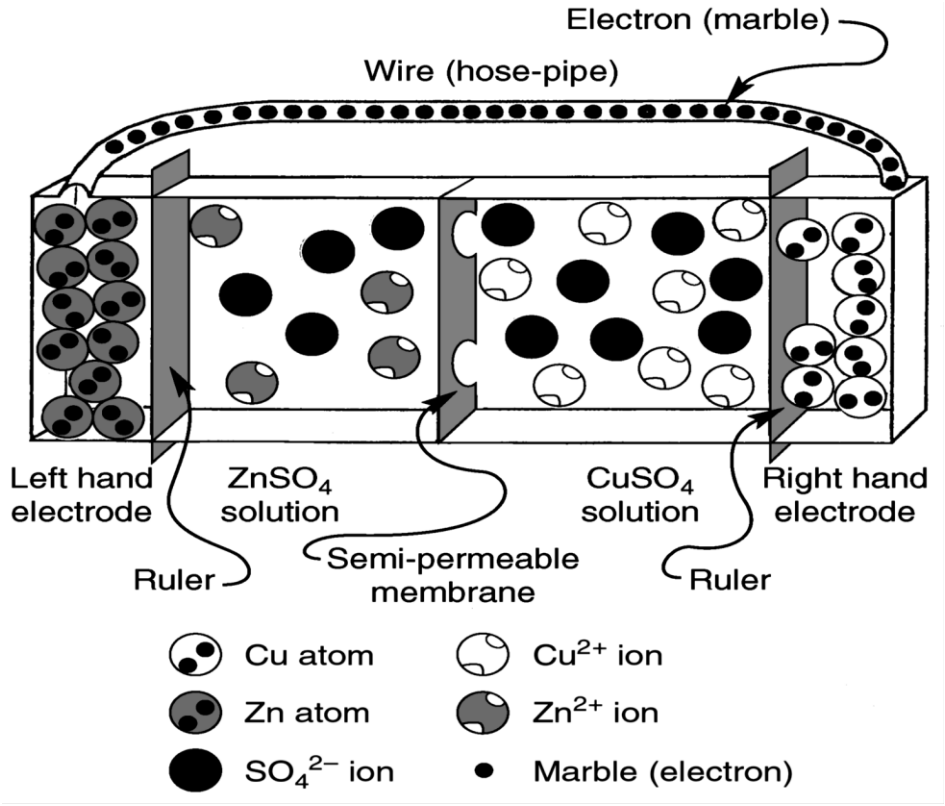




Representation 2



Representation 3



8.1 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		

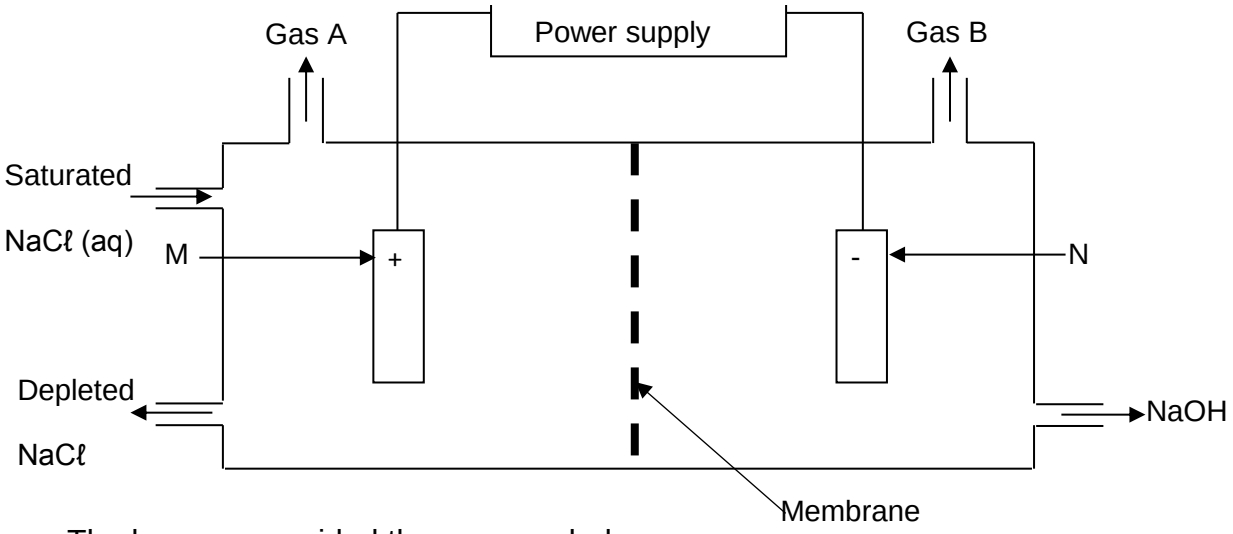
8.2 Which representation do you like most?

8.3 How would you use the representation that you like most?

CATEGORY E: CONCEPTUAL TEACHING STRATEGIES.

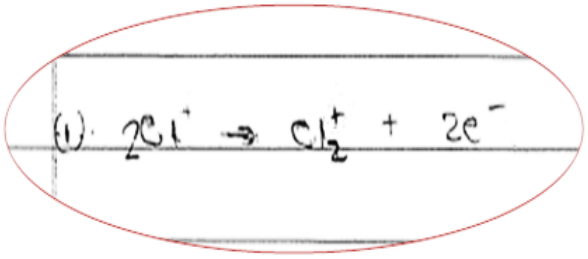
9.0 You ask learners to study the membrane cell shown in the diagram below and determine which products will form during the electrolysis of a saturated salt solution.

9.1 You ask the learners to write down the equation for the half-reaction taking place at the electrode M.

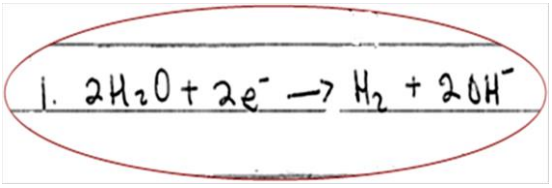


The learners provided the answers below:

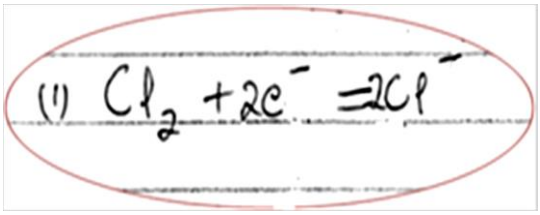
Extract 1



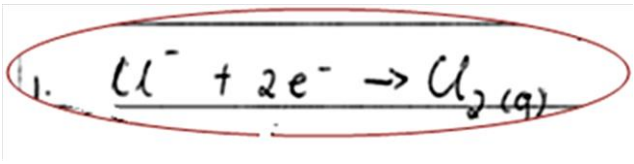
Extract 2



Extract 3



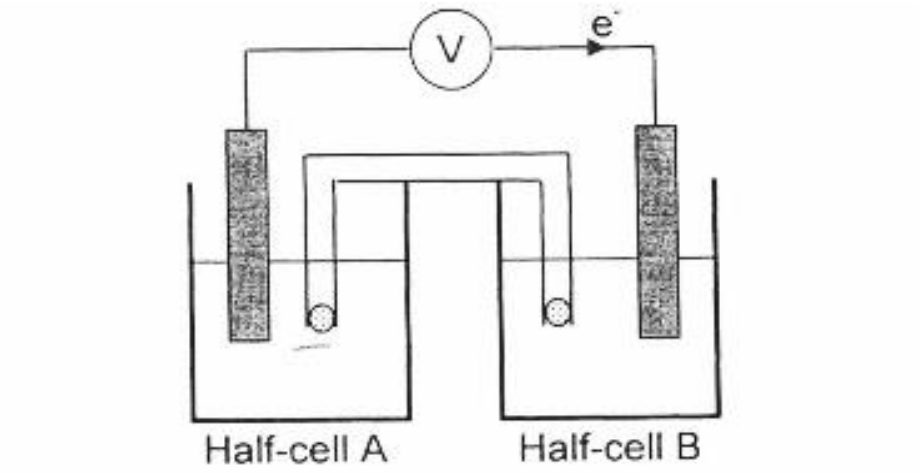
Extract 4



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

10.0 In a new class, learners are given a diagnostic test on electrochemical cells. The following diagram representing a galvanic cell consisting of Mg electrode dipped into $Mg(NO_3)_2$ solution, and a Pb electrode dipped into $Pb(NO_3)_2$ solution. They have been asked to point out the movement of ions and electrons respectively.

This question was left out in the final TSPCK instrument to reduce duration of completing the test`



A few learners write:

"Positive ions move form half-cell B to half-cell A to maintain electrical neutrality".

How will you proceed with the lesson explaining how ions and electrons move in a galvanic cell?

Thank you

Appendix A3: The Topic Specific PCK (TSPCK) Instrument

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

ELECTROCHEMISTRY TSPCK TEST

PCK Research Group

Contact Person: Prof. M. Rollnick

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

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:

Section A: Demographic information

Table 2: Background information of participants

Name					
Gender	Female		Male		
	Subject		Grade		Number of years of teaching Science
Current Teaching:					
Highest level taught (e.g. Gr 10)					Number of years teaching the grade:
	Subject		Grade		Number of years of teaching Science
Other subjects taught (Science and/ or Maths					

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 ☐ ☐

If yes, indicate how many years and how many classes in each year:

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 ions by 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, although the anode in the electrolytic cell is positive (by virtue of being connected to the positive terminal of the cell).

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

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 as 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 ideas[2] for your students to understand by 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 produces 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.	

[2]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

4.3. What topics must have been covered in chemistry before you can teach electrochemistry?

List of Topics to be taught before electrochemistry

4.4. Why is it important for learners to learn about electrochemistry? Identify reasons:

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

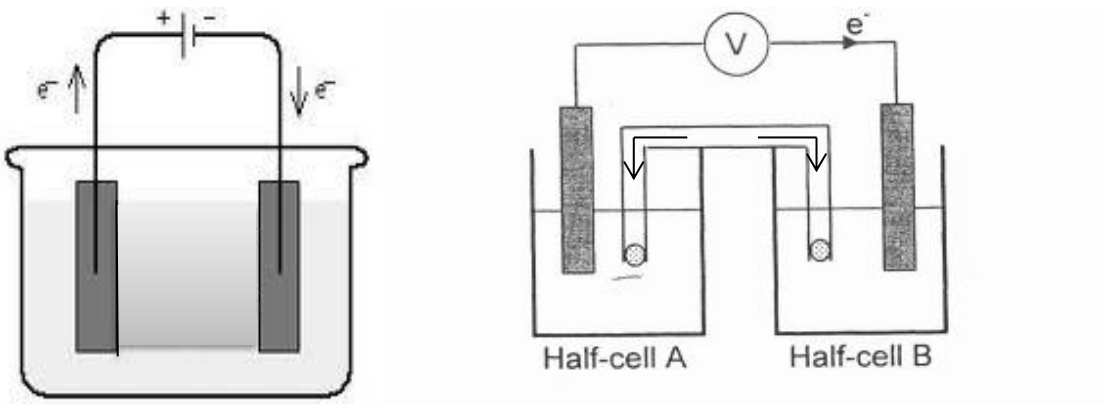
5. What concepts do you find difficult to teach in electrochemistry? Select your choice and provide reason(s) in the table below.

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		

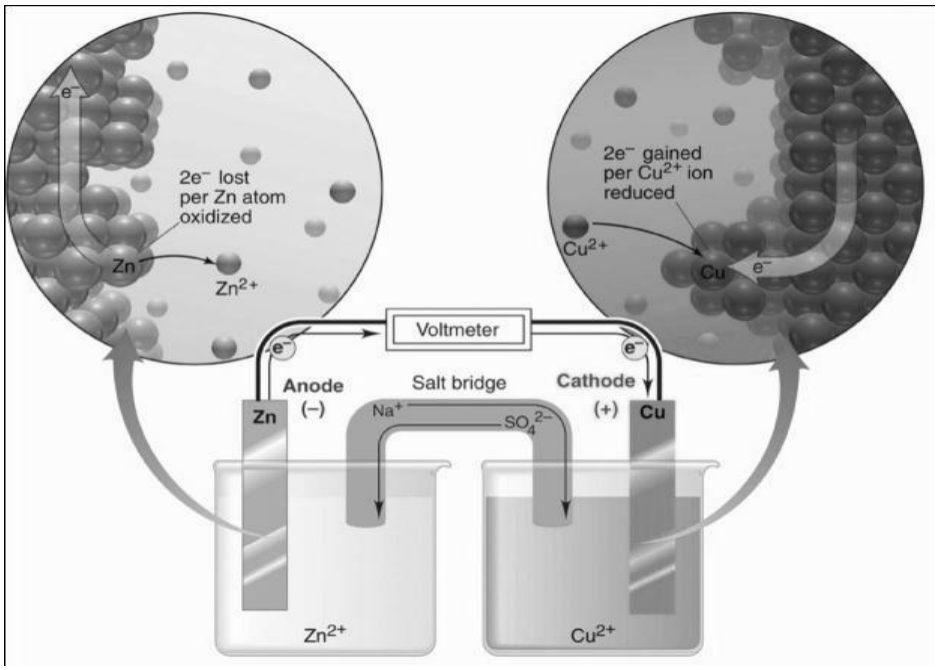
CATEGORY D: REPRESENTATIONS/ANALOGIES/MODELS

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

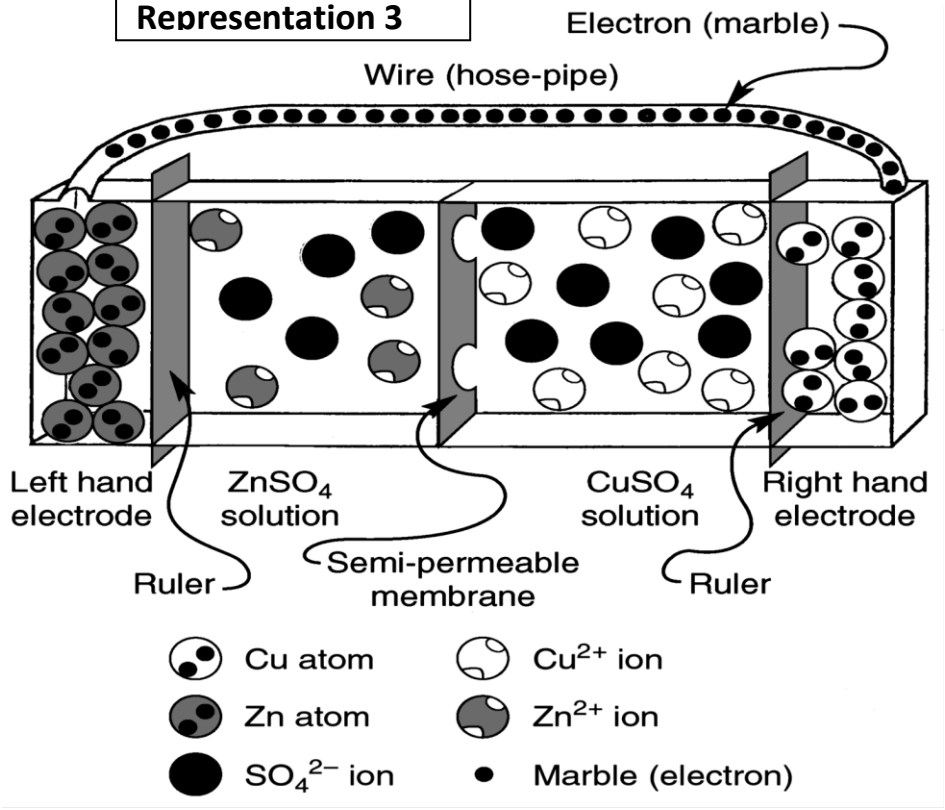
Representation 1



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?

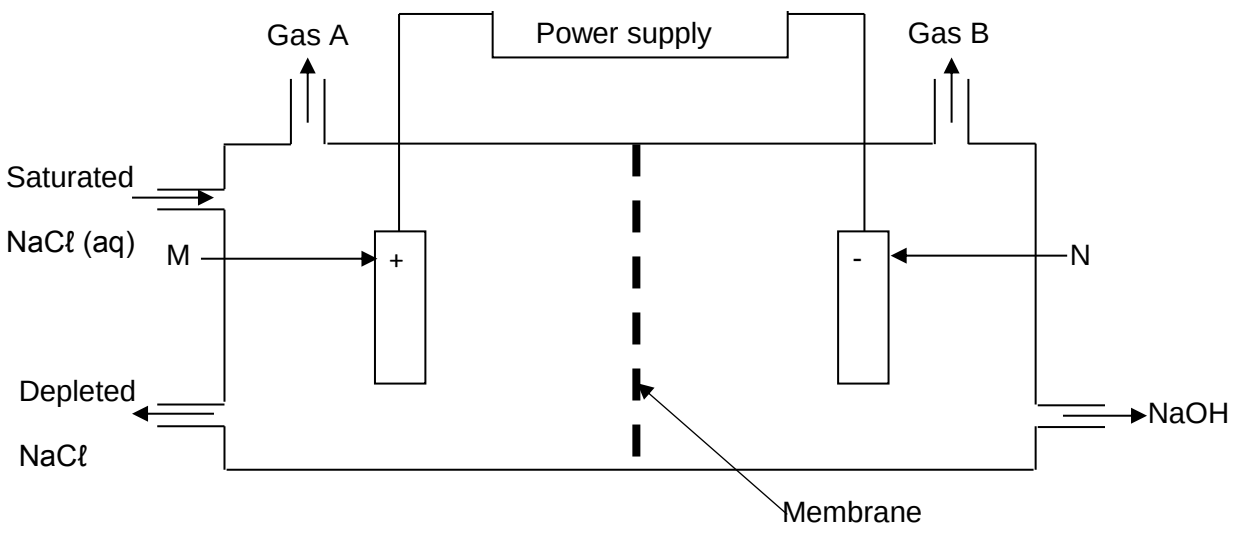
6.3. How would you use the representation that you like most?

CATEGORY E: CONCEPTUAL TEACHING STRATEGIES.

7.0. Learners are given the following task:

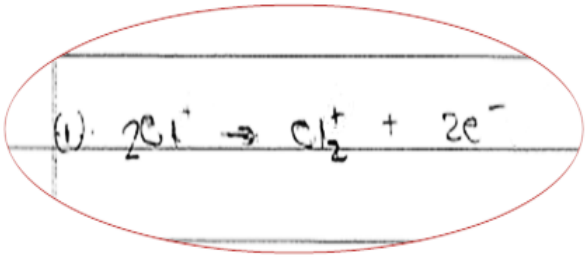
You ask learners to study the membrane cell shown in the diagram below and determine which products will form during the electrolysis of a saturated salt solution.

You ask the learners to write down the equation for the half-reaction taking place at the electrode M.

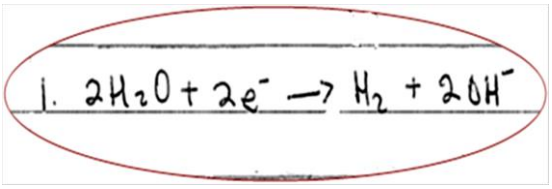


The learners provided the answers below:

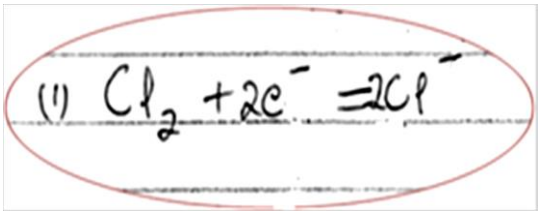
Extract 1



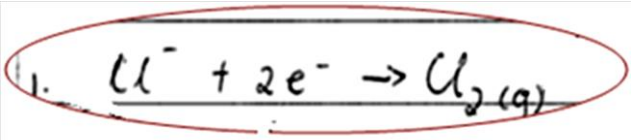
Extract 2



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 A4: Electro chemistry TSPCK test Memorandum

ELECTROCHEMISTRY TSPCK TEST MEMORANDUM

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:

Section A: Demographic information

Table 2: Background information of participants

Name			
Gender	Female	Male	
	Subject	Grade	Number of years of teaching Science
Current Teaching:			
Highest level taught (e.g. Gr 10)			Number of years teaching the grade:
	Subject	Grade	Number of years of teaching Science
Other subjects taught (Science and/ or Maths			

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 ☐ ☐

If yes, indicate how many years and how many classes in each year:

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…..**C**

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 ions by 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, although the anode in the electrolytic cell is positive (by virtue of being connected to the positive terminal of the cell).

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

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

My choice is Response…..B

3. Reflecting on your experience of teaching electrochemistry, what misconceptions have you observed as 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 ideas[3] for your students to understand by 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 produces 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.	

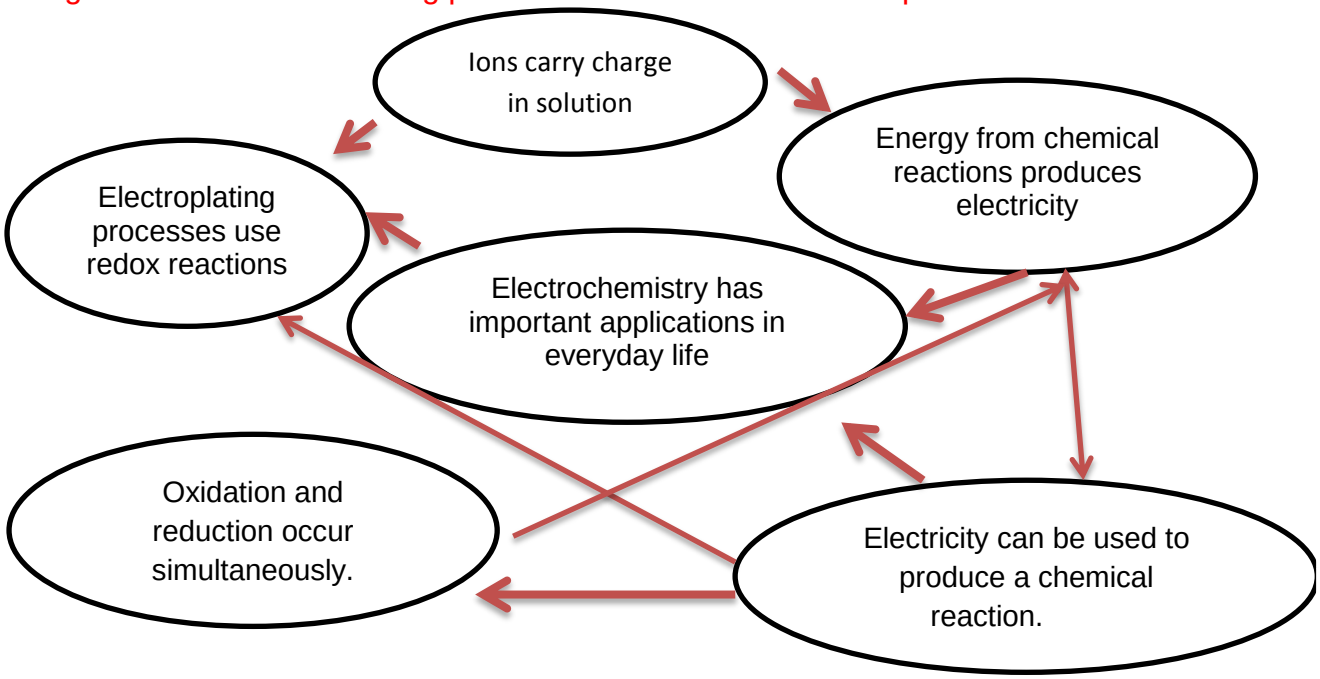
Suggested concepts and sequence	Reasons
1.	
2.	
3.	

Any 3 big ideas and justified sequence

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

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

Big idea used as the starting point in the construction of a map



An example of a concept map

The map was marked as per teacher's selected big ideas in question 4.1 above.

4.3. What topics must have been covered in chemistry before you can teach electrochemistry?

List of Topics to be taught before electrochemistry

List included some of the topics

- Chemical reactions
- Balancing equations
- Oxidation numbers and reduction numbers
- Redox reactions
- Electrolysis
- Reactivity series and electronegativity

Any relevant topic

4.4. Why is it important for learners to learn about electrochemistry? Identify reasons:

Reasons to include conceptual considerations, everyday application / intrinsic interest
Electroplating, Galvanising etc.
Battery industry, Chloralkali Industry, Extraction of metals and refining them
Water purification, Used in analytic chemistry
Detection of alcohol in drunken drivers
Detection of blood sugar level of diabetic people e.g. certain meters us redox the potential of sugar to detect sugar
for understanding of the subsequent topic

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

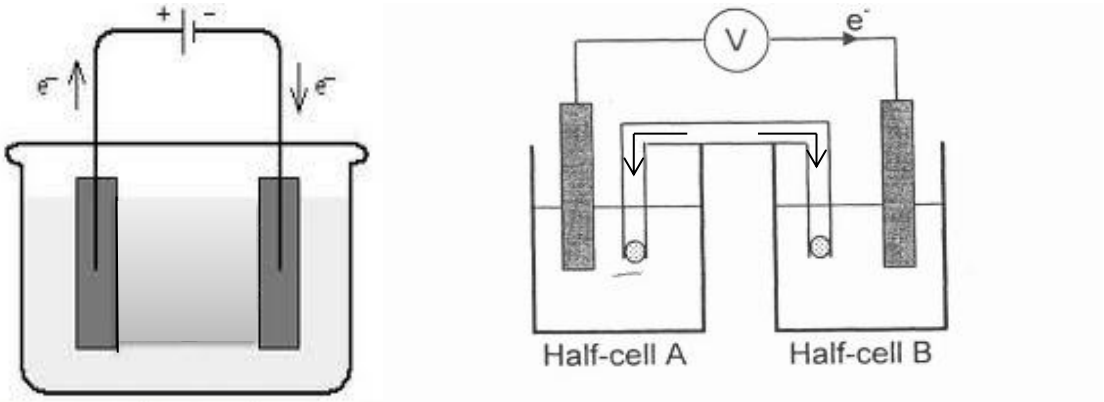
5. What concepts do you find difficult to teach in electrochemistry? Select your choice and provide reason(s) in the table below.

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		

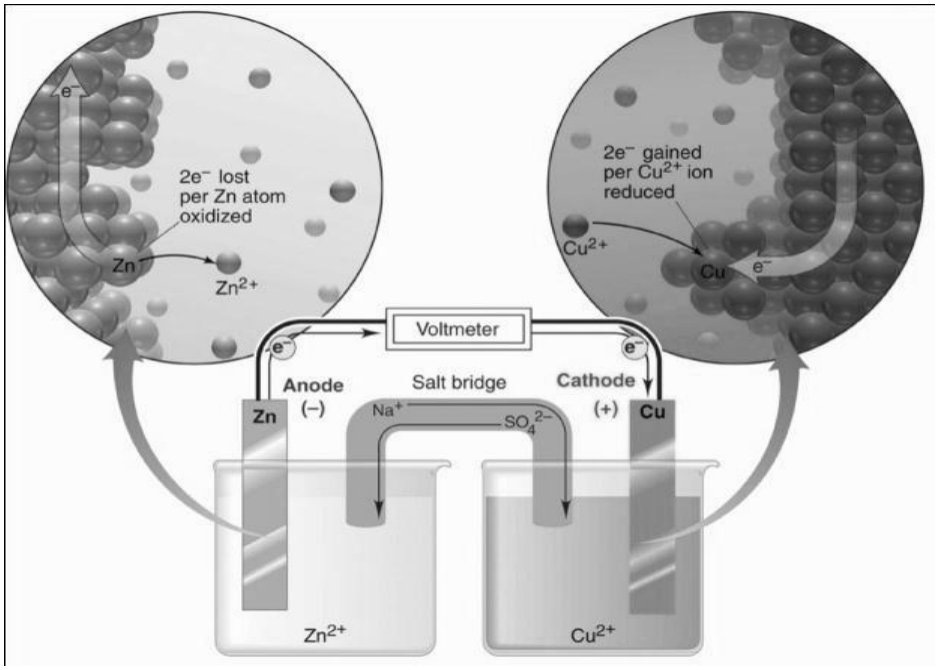
CATEGORY D: REPRESENTATIONS/ANALOGIES/MODELS

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

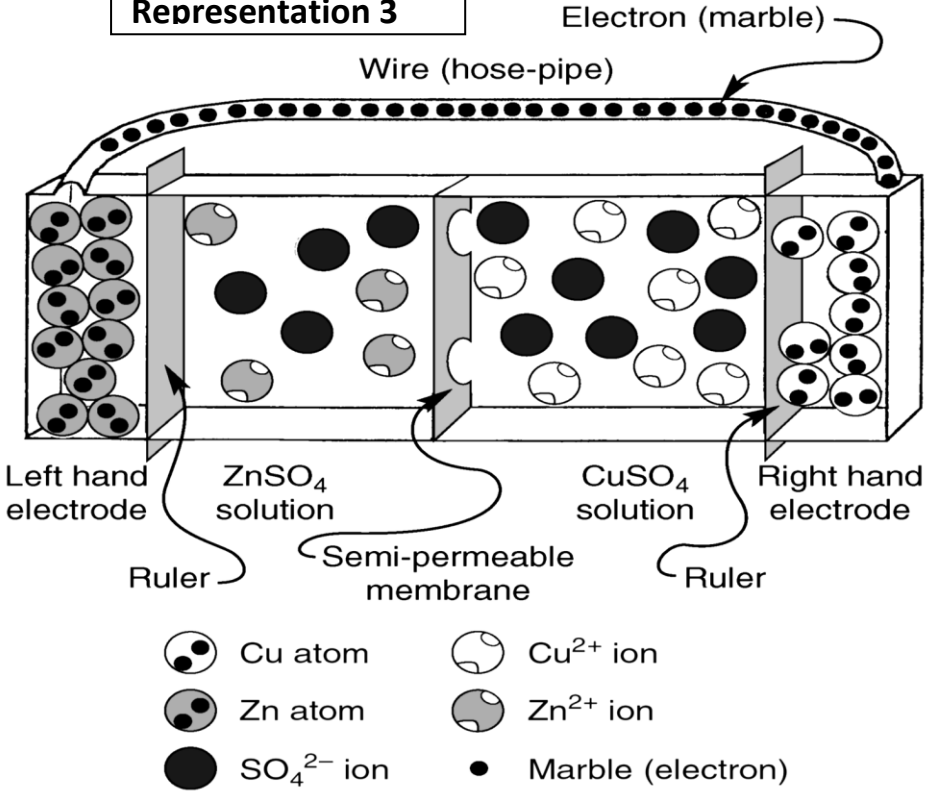
Representation 1



Representation 2



Representation 3



6.4. 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		

6.5. Which representation do you like most?

Any choice of representation

6.6. How would you use the representation that you like most?

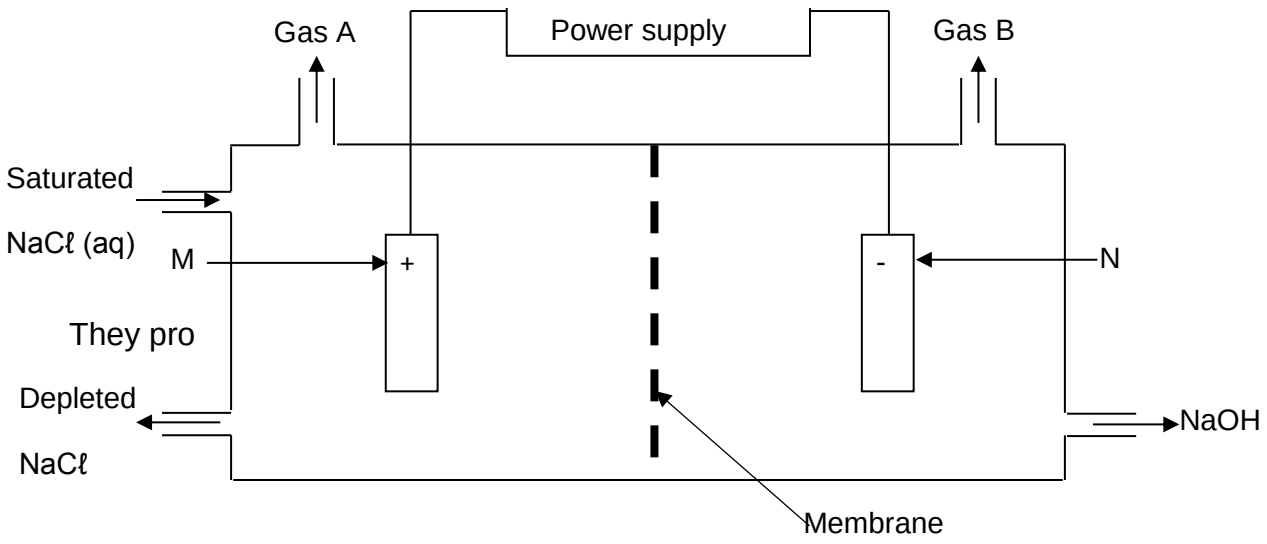
Logical explanation /Well explained choice

CATEGORY E: CONCEPTUAL TEACHING STRATEGIES.

6. Learners are given the following task:

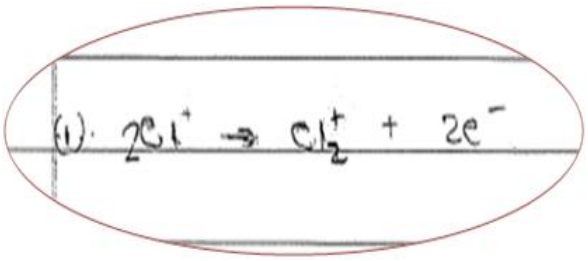
You ask learners to study the membrane cell shown in the diagram below and determine which products will form during the electrolysis of a saturated salt solution.

You ask the learners to write down the equation for the half-reaction taking place at the electrode M.

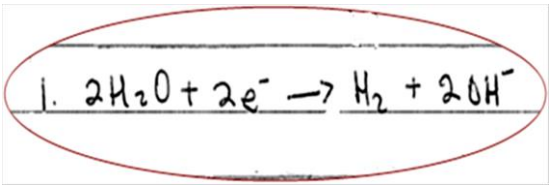


They provide the following answers below:

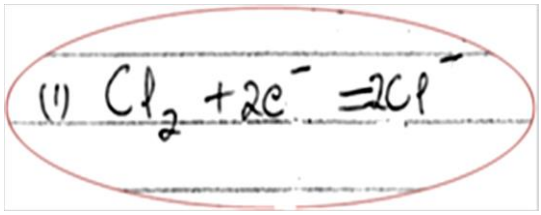
Extract 1



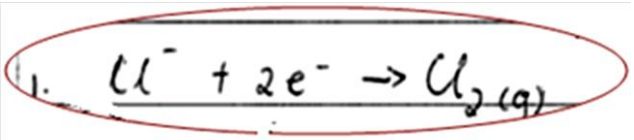
Extract 2



Extract 3



Extract 4



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

The correct answer is $2Cl^-_{(aq)} \rightarrow Cl_{2(g)} + 2e^-$

Extract 1

Error – wrong charges on ions. The learner did not have an understanding of charges on ions. The learner put the wrong charge sign (+) on both the Cℓ and also put a charge sign on Cℓ2 which is a gas and has no charge.

Extract 2

The equation in extract 3 is correct but an incorrect response to Question 7. It is incorrect because the reaction that takes place in electrode M is oxidation. This is a reduction equation that occurs at electrode N.

Extract 3

Error- chlorine gas is reduced

This is an incorrect response as this shows that chlorine gas was reduced instead of the chloride being oxidised, which led to production of Cℓ- ions,

which was incorrect. This response indicates that some learners did not know what type of reaction was taking place at electrode M.

Extract 4

The learner shows a completely wrong response to Question 7, indicating that the learner had no understanding of the concepts of electrolysis of brine.

Note: The emphasis was not placed on **phases** but on the **concept** during the marking of this question although it is important to include these Logical explanations as to how the teacher would help the learner move towards the correct concept were marked.

Thank you

Appendix A5: Electrochemistry Content Knowledge Test

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

ELECTROCHEMISTRY CONTENT KNOWLEDGE TEST

PCK Research Group

Contact Person: Prof. M. Rollnick

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

Electrochemistry Achievement Test

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: ____

Answer all questions.

Section A: Demographic information

Table 2 Background information of participants

Name					
Gender	Female		Male		
Current subject taught:					
Number of years of teaching Science					
Other subjects taught	Grade				Number of years teaching the grade:
Qualifications:	Institution where obtained				Year

Code: [ ]

1. In an electrochemical cell, conduction through the electrolyte is due to:

   Circle your choice:

   A. Electrons moving through the solution attached to ions.
   B. Electrons moving from ion to ion in the electrolyte.
   C. The movement of positive and negative ions.
   D. The movement of water molecules.
   E. Electrons moving across through the solution from one electrode to the other.

2. When the net (overall) cell reaction in a galvanic (voltaic) cell reaction reaches equilibrium, the equilibrium, the emf of the cell is equal to:

   Circle your choice:

   A. +2,00V
   B. +1,00V
   C. 0,00V
   D. -1,00V
   E. -2,00V

3. The voltage produced in the reaction $Cu_{(s)} \rightarrow Cu^{2+}_{(aq,0.1M)} + 2e^-$ is the independent of:

   Circle your choice:

   A. The size of the cathode
   B. The metal used for the anode
   C. The temperature

   Choose the correct answer and give a reason for your choice

Explain the reasons for your choice(s)above:

4. Which of the following about what happens during the electrolysis of aqueous NaCℓ is CORRECT?

   Circle your choice:

   A. Electrons are taken out of the solution and react with the Na^+ ions.
   B. At the negative electrode, electrons are repelled and they are attracted to the positive electrode through the solution.
   C. Crystallisation of sodium chloride occurs at one electrode.
   D. At the anode, chloride gas is given off while at the cathode hydrogen gas is formed.
   E. Clogging of both electrodes occurs due to the crystallisation of sodium chloride.

5. Which of the following half-reactions occurs at the anode during the electrolysis of **molten sodium chloride**?

   Circle your choice

   A. $Na^+ + e^- \longrightarrow Na$
   B. $C\ell_2 + 2e^- \longrightarrow 2C\ell^-$
   C. $2C\ell^- \longrightarrow C\ell_2 + 2e^-$
   D. $Na \longrightarrow Na^+ + e^-$
   E. $Na + e^- \longrightarrow Na^+$

6. During the electrolysis of an aqueous solution of copper chloride $CuC\ell_2$ with carbon electrodes, a brown deposit is formed at one of the electrodes. This deposit is formed when

   Circle your choice:

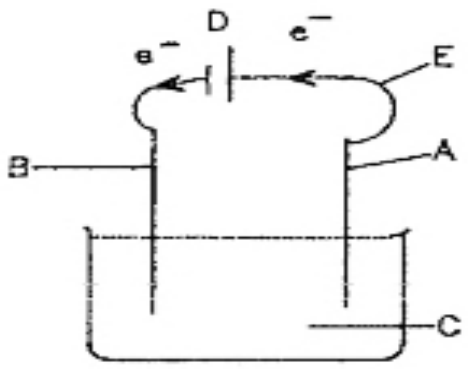
   A. Cu^{2+} ions cluster together forming the brown colour.
   B. Cu^{2+} ions react with the chloride ions forming $CuC\ell_2$ precipitate.
   C. Cu^{2+} ions are hydrated forming the brown colour
   D. Cu^{2+} ions gain electrons from the electrode forming Cu atoms and this combine to form copper metal.
   E. Cu^{2+} ions move towards the negative electrode and react with the electrode forming a brown colour.

7. The functions of a salt bridge in an galvanic (voltaic) cell is

   Circle your choice:

   A. To attract ions in solution.
   B. To transport molecules from one half-cell to the other.
   C. To made the reaction proceed faster.
   D. To ensure that one half-cell is positive and the other is negative.
   E. To maintain electrical neutrality in the two half-cells by providing ions.

8. In the electrolytic cell shown below:



   The cathode is A B C D

   Circle your choice:

9. During electrolysis, the reaction which takes place at electrode A above is

   Circle your choice:

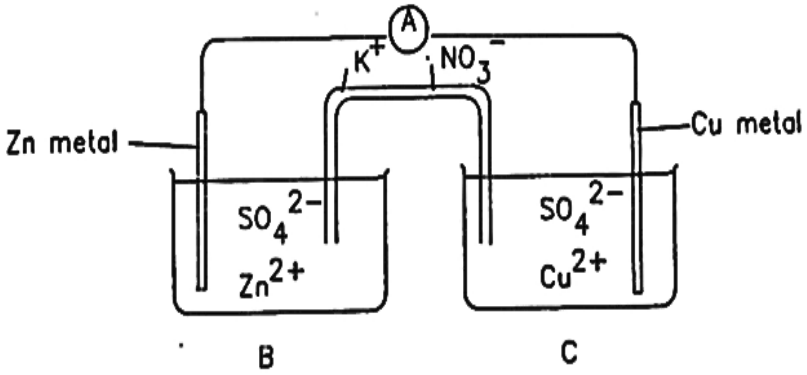
   A oxidation B. reduction

Your answer is…. Provide a detailed explanation for the answer you have chosen.

Questions 10 to 13 refer to the diagram of the galvanic (voltaic) cell shown below.

10. In the galvanic cell shown below, as the cell operates, oxidation of the zinc introduces additional Zn^{2+} into half-cell B, and reduction of Cu^{2+} leaves an excess negative charge in the half-cell C.

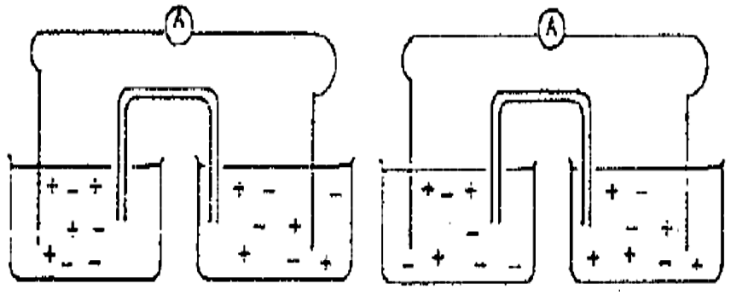
a. Indicate with arrows, the movement of all ions and the movement of electrons.



b. Label the positive and negative electrodes.

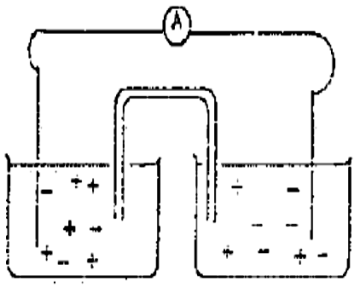
c. Which one(s) of the following series of diagrams below depict(s) the change in each half-cell as the reaction proceeds?

Note: in the following diagrams, a cation is symbolised as **+** and an anion is symbolised as **−**. An electron is symbolised *as* $\mathbf{e}^-$.

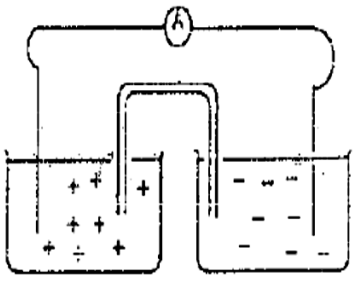


i

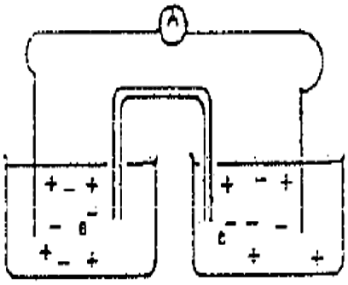
ii



iii



iv



v

Circle your choice:

A. either i or iii
B. iv only
C. i only
D. either i or iv
E. v only

11. One of the half-reactions which occurs in the galvanic cell shown in question 10 above is $Zn_{(s)} \longrightarrow Zn^{2+}_{(aq)} + 2e^-$. The electrons shown in this half-reaction comes from the

Circle your choice:

A. Dissociation of $ZnSO_4$ solution.
B. $CuSO_4$ through the salt bridge.
C. $CuSO_4$ through the external circuit.
D. Zn^{2+} ions
E. Atoms in the zinc electrode.

12. In the diagram of a galvanic cell shown in question 10:

Circle your choice:

A. It does not matter which electrode is in which electrolyte the reaction will be the same.

B. If the salt bridge were replaced with a piece of graphite bent into the same shape, then the cell would still operate.

C. The Cu^{+} and Zn^{+} ions swap with each other through the salt bridge.

D. The sulphate ions will be attracted to the positive electrode where they will be oxidised.

E. At the interface with the electrolyte, one electrode is losing electrons and the other is gaining them.

In a galvanic cell, the following occurs:

Circle your choice:

A. There is a flow of both electrons and ions through the solution from one electrode to the other.

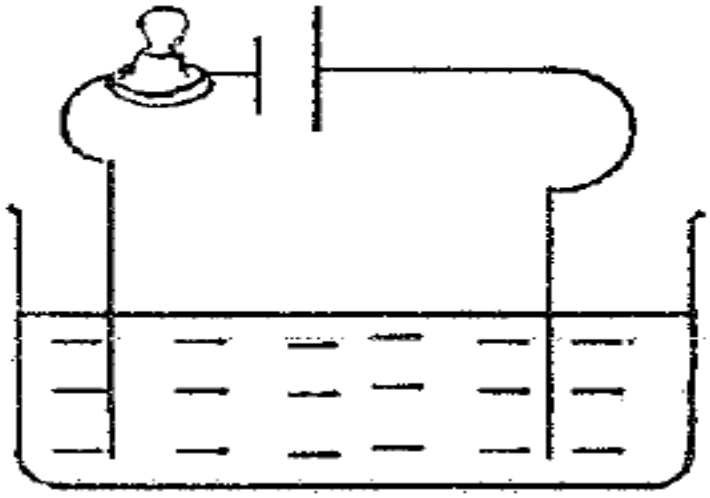
B. There is a flow of electrons from one electrode to the other in the external circuit.

C. The ions move through the wires from one electrode to the other.

D. There is flow of ions and electrons through the wires from one electrode to other connected to anode.

E. There is a flow of electrons through the wire connected to cathode and a flow of ions through the wire.

13. In the circuit represented in the diagram below, suppose the bulb is glowing brightly, the beaker could contain:



i. Sugar dissolved in water
ii. Potassium sulphate dissolved in water
iii. Molten sugar
iv. Dilute sulphuric acid
v. Molten potassium bromide

Circle your choice:

A. i only or iv only
B. ii, iv or v only
C. ii or iii only
D. ii or v only
E. i or ii only

14. The **net ionic** equation for the reaction which occurs when solutions of sodium hydroxide and hydrochloric acid are mixed is

Circle your choice

A. $Na^+_{(aq)} + OH^-_{(aq)} + C\ell^-_{(aq)} + H_3O^+_{(aq)} \rightarrow NaC\ell_{2(aq)} + 2H_2O_{(l)}$
B. $NaOH_{(aq)} + HC\ell_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$
C. $Na^+_{(aq)} + C\ell^-_{(aq)} \rightarrow NaC\ell_{2\,(s)}$
D. $Na^+_{(aq)} + OH^-_{(aq)} + H_3O^+_{(aq)} \rightarrow Na_{(aq)} + 2H_2O(l)$
E. $H_3O^+_{(aq)} + OH^-_{(aq)} \rightarrow H_2O(l)$

15. In an electrochemical cell, oxidation and reduction takes place

Circle your choice

A. At the interface of the electrodes and the electrolyte.
B. In the electrolyte
C. In the connecting wire.
D. Both in the electrolyte and in the connecting wires.
E. At the interface of the salt bridge and electrolyte.

16. Consider the reaction: $2Ag^{+}_{(aq)} + Cu_{(s)} \longrightarrow 2Ag_{(s)} + Cu^{2+}_{(aq)}$

Which of the following represents the oxidising agent in the above reaction?
Circle your choice

A. Ag^{+}
B. Ag
C. Cu^{2+}
D. Cu
E. Both Ag^{+} and Cu^{2+}

17. Which of the following statements regarding the anode of a standard galvanic cell in operation is correct?

Circle your choice

A. The anode accepts electrons.
B. The mass of the anode decreases.
C. The concentration of the electrolyte in the half-cell containing the anode initial decreases.
D. The anode is the positive terminal.
E. The anode accepts ions.

18. Which of the following characteristics are specific to an electrolytic cell?

i. The chemical reaction is spontaneous.
ii. The reaction requires energy from an electrical source.
iii. The anode is the positive electrode of the cell.

Circle your choice

A. Only i
B. Only ii
C. i and ii
D. ii and iii
E. i and iii

19. The reactions below occur in two different electrochemical cells X and Y.

Cell X: $CuCl_{2\,(aq)} \rightarrow Cu_{(s)} + Cl_{2\,(g)}$
Cell Y: $Zn_{\,(s)} + CuSO_{4\,(aq)} \rightarrow Cu_{(s)} + ZnSO_{4\,(aq)}$

Which ONE of the following correctly describes the substance that forms at the cathode of each of these cells?
Circle your choice:

	Cell X	Cell Y
A	Cl_2 (g)	Cu(s)
B	Cu(s)	Cu(s)
C	Cl_2 (g)	$ZnSO_4$(aq)
D	Cu(s)	$ZnSO_4$(aq)
E	Cl_2 (g)	Cl_2 (g)

20. Which of the values given below is the overall cell voltage and the nature of reaction occurring:

Given are the half-cell reactions: $Fe^{2+} + 2e^- \rightleftharpoons Fe$ $E^{\ominus} = -0.44V$

$Cu^{2+} + 2e^- \rightleftharpoons Cu$ $E^{\ominus} = +0.34V$

$Fe^{2+}_{(aq)} + Cu_{(s)} \rightarrow Fe_{(s)} + Cu^{2+}_{(aq)}$

i. -0.78V and the reaction is spontaneous
ii. 0.10V and the reactions is spontaneous
iii. 0.78V and the reaction is spontaneous
iv. -0.10V and the reaction is spontaneous

Which combination is true for the reaction above?

A. i only
B. ii only or iv only
C. i and iii
D. ii only
E. iii only

Thank you

Appendix A6: Content Knowledge test Memorandum

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: ____

Answer all questions.

Section A: Demographic information

Table 2 Background information of participants

Name					
Gender	Female		Male		
Current subject taught:					
Number of years of teaching Science					
Other subjects taught	Grade				Number of years teaching the grade:
Qualifications:	Institution where obtained				Year

Note: All multiple choice test items were awarded 1 mark for each correct response giving a total of 21 marks. Other marks are allocated to specific questions as explained in the respective question.

Total = 27 marks

Code:

1. In an electrochemical cell, conduction through the electrolyte is due to:
   Circle your choice:

   A. Electrons moving through the solution attached to ions.
   B. Electrons moving from ion to ion in the electrolyte.
   C The movement of positive and negative ions.
   D. The movement of water molecules.
   E. Electrons moving across through the solution from one electrode to the other.

2. When the net (overall) cell reaction in a galvanic (voltaic) cell reaction reaches equilibrium, the equilibrium, the emf of the cell is equal to:
   Circle your choice:

   A. +2,00V
   B. +1,00V
   C 0,00V
   D. -1,00V
   E. -2,00V

3. The voltage produced in the reaction $Cu_{(s)} \rightarrow Cu^{2+}_{(aq,0.1M)} + 2e^-$ is the independent of:
   Circle your choice:

   A The size of the cathode
   B. The metal used for the anode
   C. The temperature

   Choose the correct answer and give a reason for your choice

Explain the reasons for your choice(s)above:
The cathodes do not react but cause the ions either to gain (reduction) or lose electrons (oxidation).
Voltage would depend on the concentrations of substances, temperature and the type of metal used and hence voltage is measured at standard temperature and 1 molar solutions

2 marks for an explanation

4. Which of the following about what happens during the electrolysis of aqueous NaCℓ is CORRECT?
   Circle your choice:

   A. Electrons are taken out of the solution and react with the Na^+ ions.
   B. At the negative electrode, electrons are repelled and they are attracted to the positive electrode through the solution.
   C. Crystallisation of sodium chloride occurs at one electrode.
   D At the anode, chloride gas is given off while at the cathode hydrogen gas is formed.
   E. Clogging of both electrodes occurs due to the crystallisation of sodium chloride.

5. Which of the following half-reactions occurs at the anode during the electrolysis of **molten sodium chloride**?
   Circle your choice

   A. $Na^+ + e^- \rightarrow Na$
   B. $C\ell_2 + 2e^- \rightarrow 2C\ell^-$
   C $2C\ell \rightarrow {}^-C\ell_2 + 2e^-$
   D. $Na \rightarrow Na^+ + e^-$
   E. $Na + e^- \rightarrow Na^+$

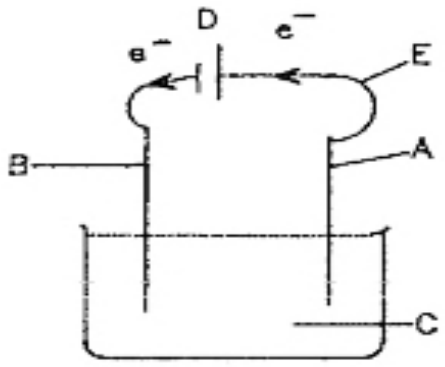
6. During the electrolysis of an aqueous solution of copper chloride $CuC\ell_2$with carbon electrodes, a brown deposit is formed at one of the electrodes. This deposit is formed when
   Circle your choice:

   A. Cu^{2+} ions cluster together forming the brown colour.
   B. A Cu2+ ion reacts with the chloride ions forming $CuC\ell_2$ precipitate.
   C. Cu^{2+} ions are hydrated forming the brown colour
   D Cu^{2+} ions gain electrons from the electrode forming Cu atoms and this combine to form copper metal.
   E. Cu^{2+} ions move towards the negative electrode and react with the electrode forming a brown colour.

7. The functions of a salt bridge in an galvanic (voltaic) cell is
   Circle your choice:

   A. To attract ions in solution.
   B. To transport molecules from one half-cell to the other.
   C. To made the reaction proceed faster.
   D. To ensure that one half-cell is positive and the other is negative.
   E To maintain electrical neutrality in the two half-cells by providing ions.

8. In the electrolytic cell shown below:



The cathode is A **B** C D

Circle your choice:

9. During electrolysis, the reaction which takes place at electrode A in the above diagram is

Circle your choice:

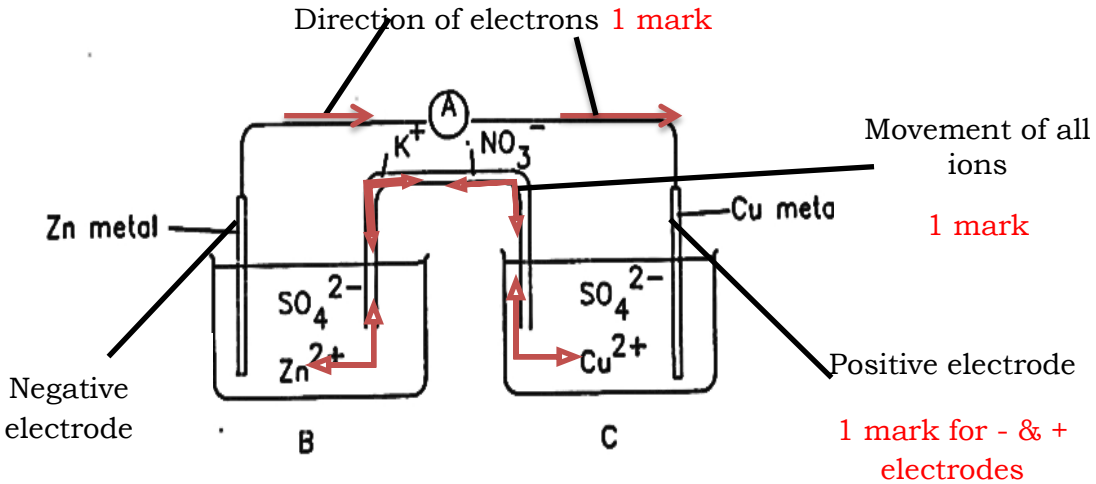
A Oxidation **B** Reduction

Your answer is**…Reduction**. Provide a detailed explanation for the answer you have chosen.
Because it is gaining electrons that are lost by the anode and repelled from the negative terminal of the battery
2 marks for an explanation

Questions 10 to 13 refer to the diagram of the galvanic (voltaic) cell shown below.

10. In the galvanic cell shown below, as the cell operates, oxidation of the zinc introduces additional Zn^{2+} into half-cell B, and reduction of Cu^{2+} leaves an excess negative charge in the half-cell C.

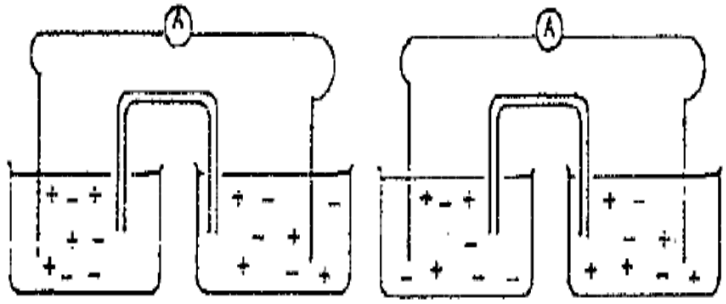
a. Indicate with arrows, the movement of all ions and the movement of electrons.



b. Label the positive and negative electrodes.

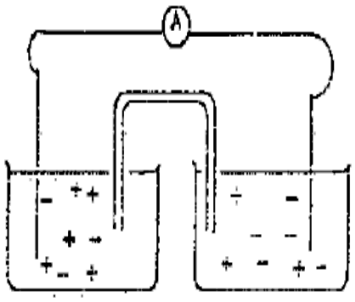
c. Which one(s) of the following series of diagrams below depict(s) the change in each half-cell as the reaction proceeds?

Note: in the following diagrams, a cation is symbolised as **+** and an anion is symbolised as **−**. An electron is symbolised *as* $\mathbf{e^-}$.

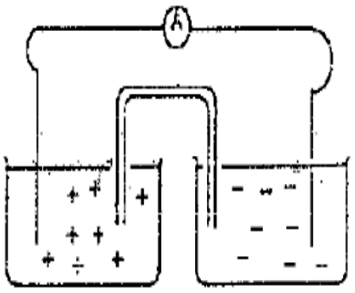


i

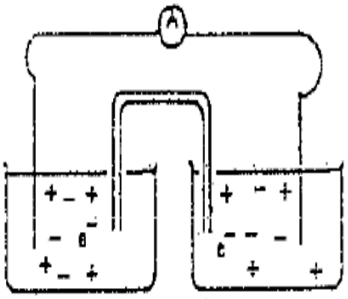
ii



iii



iv



v

Circle your choice:

A. either i or iii

B. iv only

C i only

D. either i or iv

E. v only

11. One of the half-reactions which occurs in the galvanic cell shown in question 10 above is $Zn_{(s)} \longrightarrow Zn^{2+}_{(aq)} + 2e^-$. The electrons shown in this half-reaction comes from the
Circle your choice:

A. Dissociation of $ZnSO_4$ solution.

B. $CuSO_4$ through the salt bridge.

C. $CuSO_4$ through the external circuit.

D. Zn^{2+} ions

E Atoms in the zinc electrode.

12. In the diagram of a galvanic cell shown in question 10:

Circle your choice:

A. It does not matter which electrode is in which electrolyte the reaction will be the same.

B. If the salt bridge were replaced with a piece of graphite bent into the same shape, then the cell would still operate.

C. The Cu^{+} and Zn^{+} ions swap with each other through the salt bridge.

D. The sulphate ions will be attracted to the positive electrode where they will be oxidised.

E At the interface with the electrolyte, one electrode is losing electrons and the other is gaining them.

13. In a galvanic cell, the following occurs:

Circle your choice:

A. There is a flow of both electrons and ions through the solution from one electrode to the other.

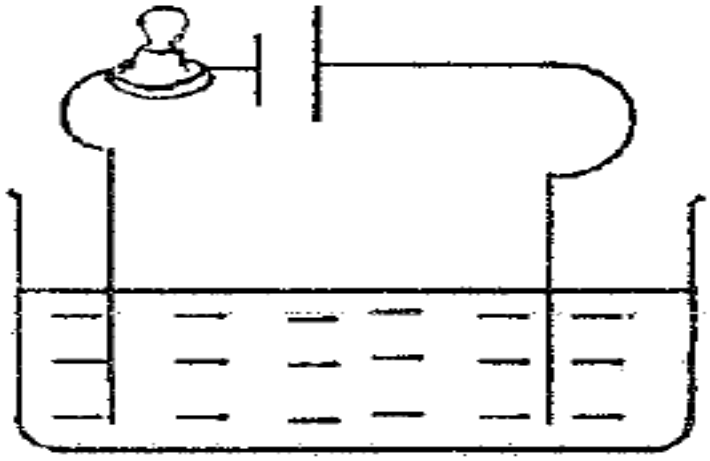
B There is a flow of electrons from one electrode to the other in the external circuit.

C. The ions move through the wires from one electrode to the other.

D. There is flow of ions and electrons through the wires from one electrode to other connected to anode.

E. There is a flow of electrons through the wire connected to cathode and a flow of ions through the wire.

14. In the circuit represented in the diagram below, suppose the bulb is glowing brightly, the beaker could contain:



i. Sugar dissolved in water

ii. Potassium sulphate dissolved in water

iii. Molten sugar

iv. Dilute sulphuric acid

v. Molten potassium bromide

Circle your choice:

A. i only or iv only

B ii, iv or v only

C. ii, iii or v only

D. ii or v only

E. i or ii only

15. The **net ionic** equation for the reaction which occurs when solutions of sodium hydroxide and hydrochloric acid are mixed is

Circle your choice

A. $Na^+_{(aq)} + OH^-_{(aq)} + C\ell^-_{(aq)} + H_3O^+_{(aq)} \rightarrow NaC\ell_{2(aq)} + 2H_2O_{(l)}$

B. $NaOH_{(aq)} + HC\ell_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$

C. $Na^+_{(aq)} + C\ell^-_{(aq)} \rightarrow NaC\ell_{2\,(s)}$

D. $Na^+_{(aq)} + OH^-_{(aq)} + H_3O^+_{(aq)} \rightarrow Na_{(aq)} + 2H_2O(l)$

E $H_3O^+_{(aq)} + OH^-_{(aq)} \rightarrow H_2O(l)$

16. In an electrochemical cell, oxidation and reduction takes place

Circle your choice

A At the interface of the electrodes and the electrolyte.

B. In the electrolyte

C. In the connecting wire.

D. Both in the electrolyte and in the connecting wires.

E. At the interface of the salt bridge and electrolyte.

17. Consider the reaction: $2Ag^{+}_{(aq)} + Cu_{(s)} \longrightarrow 2Ag_{(s)} + Cu^{2+}_{(aq)}$

Which of the following represents the oxidising agent in the above reaction?

Circle your choice

A. Ag^{+}

B Ag

C. Cu^{2+}

D. Cu

E. Both Ag^{+} and Cu^{2+}

18. Which of the following statements regarding the anode of a standard galvanic cell in operation is correct?

Circle your choice

A. The anode accepts electrons.

B The mass of the anode decreases.

C. The concentration of the electrolyte in the half-cell containing the anode initial decreases.

D. The anode is the positive terminal.

E. The anode accepts ions.

19. Which of the following characteristics are specific to an electrolytic cell?

i. The chemical reaction is spontaneous.
ii. The reaction requires energy from an electrical source.
iii. The anode is the positive electrode of the cell.

Circle your choice

A. Only i

B. Only ii

C. i and ii

D ii and iii

E. i and iii

20. The reactions below occur in two different electrochemical cells X and Y.

Cell X: $CuCl_{2\,(aq)} \rightarrow Cu_{(s)} + Cl_{2\,(g)}$
Cell Y: $Zn_{\,(s)} + CuSO_{4\,(aq)} \rightarrow Cu_{(s)} + ZnSO_{4\,(aq)}$

Which ONE of the following correctly describes the substance that forms at the cathode of each of these cells?
Circle your choice:

	Cell X	Cell Y
A	Cl_2 (g)	Cu(s)
B	Cu(s)	Cu(s)
C	Cl_2 (g)	$ZnSO_4$(aq)
D	Cu(s)	$ZnSO_4$(aq)
E	Cl_2 (g)	Cl_2 (g)

21. Which of the values given below is the overall cell voltage and the nature of reaction occurring:

Given are the half-cell reactions: $Fe^{2+} + 2e^- \rightleftharpoons Fe$ $E^{\ominus} = -0.44V$

$Cu^{2+} + 2e^- \rightleftharpoons Cu$ $E^{\ominus} = +0.34V$

$Fe^{2+}{}_{(aq)} + Cu_{(s)} \rightarrow Fe_{(s)} + Cu^{2+}{}_{(aq)}$

i. -0.78V and the reaction is spontaneous
ii. 0.10V and the reactions is spontaneous
iii. 0.78V and the reaction is spontaneous
iv. -0.10V and the reaction is spontaneous

Which combination is true for the reaction above?

A. i only
B. ii only or iv only
C. i and iii
D. ii only
E iii only

Thank you!

Appendix A7: Ethics requirements

INFORMATION SHEET TO TEACHERS

Date: 13 October 2012

Dear: _____

My name is Musawenkosi Ndlovu and I am a student in the School of Education at the University of the Witwatersrand, I invite you_____ to be a participant in the research that I wish to conduct. My research is aimed at developing and validation an instrument that could be used to measure South Africa's Physical Science teachers' understanding of the topic of electrochemistry and how they teach this topic. I am also interested in studying how Physical Science teachers transform their content knowledge on electrochemistry into a form that can be understood by their learners in their classrooms. I will use data collected to compile a research report to be submitted to the abovementioned institution towards partial fulfilment of the requirements of my studies in the Science education. For my study, I need grade 12 Physical Sciences teachers who have taught electrochemistry before and preferable are in their third year and above of teaching grade 10 to 12 in the current year. My data collecting procedures entail administering a conceptual diagnostic test as well as a test on strategies you use for teaching this topic such that your learners understand the concepts. I am asking for your permission for both administering a test on you and using your results for my research. The results of the test will only be used for this purpose of teaching and research purposes.

I will need approximately 80 minutes of your time to complete test.

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

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

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

Please let me know if you require any further information. Thank you very much for your help.

Yours sincerely

M. Ndlovu 

Name: Musawenkosi Ndlovu
Address: Ibhongo Secondary School
133 Dinzulu and Chris Hani Rd
Tshiawelo
1818

E mail: nkobmusa@gmail.com
Cell: 0828625570

Other contacts: PCK Research group

Contact Person: Prof. Marissa Rollnick
E mail: Marissa.Rollnick@wits.ac.za
Telephone Numbers: 0823745574

Elizabeth Mavhunga
E mail: Elizabeth.Mavhunga@wits.ac.za
Telephone Numbers: 0822045733

Wits School of Education: Marang Centre for Maths* Science Education

Appendix A8: Teacher consent form

CONSENT FORM TEACHERS' QUESTIONNAIRE

Please fill and return the slip below indicating your willingness to write diagnostic tests for my voluntary research project.

Permission for use of a questionnaire

I, _____(Name & Surname) _____(Institution) Give/ do not give consent to write the diagnostic test to check my understanding of the topic and how I teach topic on electrochemistry as detailed in the information sheet above. Delete in the inapplicable.

I have read the above information and I understand its contents. I realise that there is no harm will come on me as result of participating in this study, and that this study being conducted for the purposes of improving the learning and teaching of science especially in electrochemistry and my practice.

[ ] I further consent for the results the report or for teaching only.

I realise that this research will not interfere with my teaching as electrochemistry forms part of grade 12 knowledge areas of chemical systems.

[ ] I am fully aware that my results will not result in me losing my job in the event that they are not favourable. And I may withdraw anytime if I choose too. This may not disadvantage me in any way.

[ ] I have no objection in writing the test/ I wish my personal details will be as confidential as possible. Pleas delete the option which is not applicable.

[ ] I consent the test results will be used in the research report, but they will be reported such that my identity will be kept anonymous and my performance is confidential.

[ ] I know that I may withdraw anytime and [ ] I am aware that researcher will keep all information confidential in all academic writing.

[ ] I am aware that my test script will be destroyed after 3-5 years after completion of the project.

Teacher's signature:_____ Date: _____

Address: _____ Contact Number: _____

Appendix A9: Ethics clearance certificate

Wits School of Education

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

Student Number: 584662
Protocol Number:
2012ECE117C

Date: 31-Jul-2012

Dear Musawenkosi Ndlovu

Application for Ethics Clearance: Master of Science

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

The Design of an Instrument to Measure the Topic Specific Pedagogical Content Knowledge of Physical Science Teachers in Electrochemistry

The committee recently met and I am pleased to inform you that clearance was granted. The committee was delighted about the ways in which you have taken care of and given consideration to the ethical dimensions of your research project. Congratulations to you and your supervisor!

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

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

All the best with your research project.

Yours sincerely

M Mabeta

Matsie Mabeta
Wits School of Education

011 717 3416

CC Supervisor: Prof M Rollnick

Appendix A10: Demographic information of participants (N=21)

Code	Gender	Highest /relevant Qualification	Teaching experience	No of years teaching electrochemistry	Current subject taught (grade 12)
MN01(Lolo)	Female	BED Hon, B (PAED), ACE (PS)	15	15	PS*
MN02 (Ben)	Male	BSc (chem/Physics)	10	6	PS
MN03 (Dola)	Female	BED (Chem), ACE (PS)	6	4	ML*
MN04 (Sammy)	Male	BSc Ed (Chemistry/ physics), ACE	17	5	PS
MN05 (Sheena)	Male	BSc (PS), PGDE (PS), NDHRM	17	10	PS
MN06 (Kashmiri)	Female	BSc (PS),PHED,A+,N+	15	15	PS
MNO7 (Greg)	Male	BSc, HED (Maths),ACE (PS) Sciences)	17	17	PS
MN08 (Suku)	Female	BSc Agric Management, Diploma Ed (chemistry/physics/biology)	23	4 in RSA	PS
MN09 (Susan)	Male	Bed (PS)	10	10	PS
MN10 (Andy)	Male	BED	6	6	PS
MN11 (Edwin)	Male	Nat Dip Chem Eng, PGCE (Primary)	10	Maths	Maths
MN12 (Gugu)	Female	BSc General (Biochemistry), Diploma in Education (chemistry/physics/Biology)	16	16	PS
MN13 (Tanya)	Female	BSc Ed (Chemistry/ physics),ACE	6	1 in 2003	PS
MN14(Tiane)	Female	SED (PS/maths), ACE (Physical sciences)	6	4	PS
MN15 (Shelton)	Male	STD (PS/maths), ACE, Certificate (Chemistry/physics)	12	3	PS
MN16 (Vusi)	Male	B.Ed.(Physics/chemistry), MED Science education	10	5 in RSA	PS
MN17 (Mbali)	Female	PTD,SEC,HED,ACE(PS)	16	11	PS
MN18 (Leon)	Male	BSc (Ed)	12	6 in RSA	PS
MN19 (Frank)	Male	BSc (chemistry/Biochemistry),Diploma in Education	17	8 in RSA	PS
MN20 (Xola)	Female	Diploma in Education, BSc in Agriculture & management	18	7 in RSA	PS

Note: *PS-Physical sciences, *ML-Mathematical Literacy

Appendix 11: Modification of Topic Specific PCK Rubric

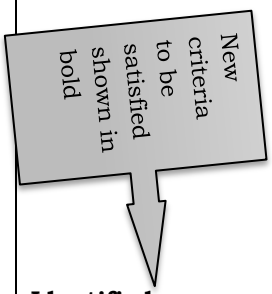
Table X: Extract from Rubric for Topic specific PCK tool (adapted from Mavhunga & Rollnick (2012).

TSKfT Components	Limited(1)	(2) Basic	(3) Developing	Exemplary (4)
Curriculum Saliency	• Identified concepts are a mixture of Big Ideas and subordinate ideas • Identified subordinate ideas mixed with those Big Ideas of other topics • Identified pre-concepts are a mix including those to be taught in current topic • Sequencing no value due to mixed concepts • Reasons given for importance of topic limited to general benefit of education	• Identifies at least 2 Big Ideas • Not all 2 Big ideas have subordinate concepts identified • Sequencing can be followed but has at least one illogical placing of key concepts (Big Ideas) and for the suggested pre-concepts. • Identified pre-concepts refer to concepts generally regarded as basic for the subject/ discipline • Reasons given for importance of topic exclude conceptual considerations such as scaffolding/sequential development of understanding for other topics in the subject.	• Identifies at least 3 Big Ideas • Identifies subordinate ideas and shows links to Big ideas with no explanations • Provides logical sequence of concepts of all three Big Ideas, and pre-concepts largely logical with one illogical placing • Identified pre-concepts includes those used in the definition of current topic • Reasons given for importance of topic include reference to conceptual considerations such as scaffolding/sequential development of understanding of other topics in the subject (however topics not specified)	• Identifies at least 3 Big Ideas • Identifies subordinate ideas and explains links • Provides logical sequence of all three Big Ideas and that for pre-concepts. • Identified pre-concepts include those used in the definitions and in other Big Ideas (key concepts) of the current topic. • Reasons given for importance of topic include conceptual considerations such as scaffolding/sequential development of understanding for specified other subsequent topics in the subject.

For instance, in the original rubric, the teacher who had identified 1 big idea could be classified as having 'limited' PCK whereas in the modified rubric the teacher could be having seen as having 'basic' TSPCK and the more the number of big ideas could show progressing from 'developing' up to 'exemplary' TSPCK. The modifications are shown on Table 7.1a below.

Table 7.1a shows a modified TSPCK rubric

TSPCK Components	Limited(1)	(2) Basic	(3) Developing	Exemplary (4)
Curricular Saliency	**Only subordinate ideas identified** Sequencing no value due to mixed concepts or no sequence provided at all Identified subordinate ideas mixed with those Big Ideas of other topics **Map lacks logic** **No linking words** **Identified pre concepts lack coherence with current topics, do not relate to concept map** Reasons given for importance of topic	**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** 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** **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	**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 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** **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**	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** 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**



TSPCK Components	Limited(1)	(2) Basic	(3) Developing	Exemplary (4)
	limited to general benefit of education One reasons given or gives a general statement such as " has important applications)	Reasons given for importance of topic exclude conceptual considerations such as scaffolding/sequential development of understanding for other topics in the subject. **But may include application to everyday life**	Reasons given for importance of topic 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**	Reasons given for importance of topic include 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**

In category D, the rubric now contains two rows having description of criteria that have be to be satisfied, for use and how to use the representation chosen. The 'how' to use criterion was absent in the original authors' rubric. The modification is shown in bold.

Extract from Mavhunga & Rollnick (2012) original rubric is shown below.

TSPCK Components	• Limited(1)	• (2) Basic	• (3) Developing	• Exemplary (4)
Representations	• 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

Ndlovu's rubric after modifications

TSPCK Components	Limited(1)	(2) Basic	(3) Developing	Exemplary (4)
Category D Representations/ analogies /models	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
New Criterion	**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**

Appendix A12: The Final Topic Specific rubric TSPCK used in the study

TSPCK rubric used as a rating scheme– based on Topic Specific Knowledge for Teaching

TSPCK Components	Limited(1)	(2) Basic	(3) Developing	Exemplary (4)
Learner Prior Knowledge including misconceptions	No identification/No acknowledgement/No consideration of student prior knowledge or misconceptions 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
	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
Curricular saliency	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 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
	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	Identifies subordinate ideas and shows links to Big ideas with no linking words Uses at least 2 big ideas as a starting point	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

TSPCK Components	Limited(1)	(2) Basic	(3) Developing	Exemplary (4)
	Identified pre concepts lack coherence with current topics, do not relate to concept map Reasons given for importance of topic limited to general benefit of education One reason given or gives a general statement such as " has important applications"	Some subordinate ideas relate to big ideas 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 Reasons given for importance of topic exclude conceptual considerations such as scaffolding/sequential development of understanding for other topics in the subject. But may include application to everyday life	Subordinate ideas relate to Big ideas on map 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 Reasons given for importance of topic 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	Reasons given for importance of topic include 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
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

TSPCK Components	Limited(1)	(2) Basic	(3) Developing	Exemplary (4)
Representations / analogies /models	Limited to use of only macroscopic or symbolic representation of scientific notation i.e. formulae/equations No discussion on how the representation is going to be used or suggested use in appropriate, unworkable or unsafe	Use of macroscopic representation (analogies, demos, etc.) and Use of scientific symbolic representation for different aspects of a concept not enforcing a specific aspect. Discussion lacks logic or clarity List of concepts given with no explanation on how representation is going to be used Suggested procedure impractical	Use of macroscopic representation (analogies, demos, etc.) and/or Use of scientific symbolic representation to enforce a specific aspect of a concept 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	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 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
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 A13: Validation the TSPCK instrument

Person–Item Reliability summary statistics

```
TABLE 3.1 musa data                                ZOU603WS.TXT  Aug 28  1:11 2013
INPUT: 21 Person  5 Item  REPORTED: 21 Person  5 Item  4 CATS    MINISTEP 3.75.0
-------------------------------------------------------------------------------
     SUMMARY OF 21 MEASURED Person
-------------------------------------------------------------------------------
|          TOTAL                          MODEL          INFIT        OUTFIT    |
|          SCORE     COUNT     MEASURE    ERROR      MNSQ   ZSTD   MNSQ   ZSTD |
|-----------------------------------------------------------------------------|
| MEAN      11.8       5.0       -1.37     1.19       .87    -.3    .77    -.1 |
| S.D.       2.4        .0        3.55      .07       .87    1.1    .92     .8 |
| MAX.      17.0       5.0        7.72     1.31      3.45    2.2   3.33    1.5 |
| MIN.       7.0       5.0       -7.85     1.09       .16   -1.2    .13   -1.0 |
|-----------------------------------------------------------------------------|
| REAL RMSE   1.38 TRUE SD    3.28  SEPARATION 2.38   Person RELIABILITY  .85 |
|MODEL RMSE   1.20 TRUE SD    3.35  SEPARATION  2.80  Person RELIABILITY  .89 |
| S.E. OF Person MEAN = .79                                                   |
-------------------------------------------------------------------------------
Person RAW SCORE-TO-MEASURE CORRELATION = .99
CRONBACH ALPHA (KR-20) Person RAW SCORE "TEST" RELIABILITY = .84
      SUMMARY OF 5 MEASURED Item
-------------------------------------------------------------------------------
|          TOTAL                          MODEL          INFIT        OUTFIT    |
|          SCORE     COUNT     MEASURE    ERROR      MNSQ   ZSTD   MNSQ   ZSTD |
|-----------------------------------------------------------------------------|
| MEAN      49.6      21.0         .00      .59       .86    -.5    .77    -.2 |
| S.D.       8.9        .0        3.15      .05       .28    1.1    .44    1.0 |
| MAX.      64.0      21.0        4.13      .67      1.27     .9   1.61    1.3 |
| MIN.      37.0      21.0       -5.42      .54       .42   -2.4    .32   -1.8 |
|-----------------------------------------------------------------------------|
| REAL RMSE    .60 TRUE SD    3.09  SEPARATION  5.14  Item   RELIABILITY  .96 |
|MODEL RMSE    .59 TRUE SD    3.09  SEPARATION  5.26  Item   RELIABILITY  .97 |
| S.E. OF Item MEAN = 1.57                                                    |
-------------------------------------------------------------------------------
UMEAN=.0000 USCALE=1.0000
Item RAW SCORE-TO-MEASURE CORRELATION = -1.00
105 DATA POINTS. LOG-LIKELIHOOD CHI-SQUARE: 91.78 with 78 d.f. p=.1363
Global Root-Mean-Square Residual (excluding extreme scores): .3473
```

Good person reliability

Good item reliability index

All reliability indices are within the range of accepted Infit/Outfit statistics (-2 and +2)-quite pleasing.

Appendix A14: Item measure statistics

Fig. x shows the summary statistics of item difficulty hierarchy in descending order. All values are within the -2 and +2 range of Fit statistics. Thus, confirming the validity of the developed TSPCK instrument.

TABLE 13.1 musa data ZOU603WS.TXT Aug 28 1:11 2013
INPUT: 21 Person 5 Item REPORTED: 21 Person 5 Item 4 CATS MINISTEP 3.75.0

Person: REAL SEP.: 2.38 REL.: .85 ... Item: REAL SEP.: 5.14 REL.: .96

Item STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PT-MEASURE CORR.	PT-MEASURE EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Item
5	37	21	4.13	.59	.89	-.2	.74	-.1	.85	.81	85.7	81.2	Conceptual teaching strategies
4	46	21	1.34	.54	1.27	.9	1.61	1.3	.86	.77	61.9	76.5	Representations
2	48	21	.76	.54	.42	-2.4	.32	-1.8	.82	.77	95.2	78.1	Curricular saliency
3	53	21	-.81	.59	.72	-.8	.62	-.4	.75	.79	90.5	80.9	What is difficult or easy
1	64	21	-5.42	.67	1.00	.1	.57	-.2	.59	.71	95.2	85.6	Learner prior knowledge
MEAN	49.6	21.0	.00	.59	.86	-.5	.77	-.2			85.7	80.5	
S.D.	8.9	.0	3.15	.05	.28	1.1	.44	1.0			12.4	3.1	

Most difficult test item

Appendix A15: Standardized residual variance scree plot of items

The scree plot shows the amount of variance in teachers' scores that is explained by test items which is accounted for by the Rasch model. The plot further provides evidence of the validity of the developed TSPCK instrument if the data collected using the instrument fits the Rasch model perfectly. Issues of validity of the instrument were dealt with in detail in chapter 5. This section is an extension of validity issues done out of interest. In addition to estimation items and person reliabilities, the Rash model explains variance in observed raw scores of physical science teachers that is explained by person and item measures. The Rasch model also estimates randomness in the data. Table xxx shows tentative guidelines of accepted critical values of variance that data collected with the instrument is assessed against to measure if data fits the Rasch model perfectly. The variance explained by the 1st contrast should always be less than 2.0 Eigenvalue units (Linacre, 2012, p. 353) to indicate unidimensionality of the Rasch model. Linacre added that values greater than 2.0 Eigenvalue units usually indicate that there could be a second dimension that is accounting for the observed variance.

Table xxx: Standard residual variance table (adapted from Linacre, 2012).

TABLE OF STANDARD RESIDUAL variance (in Eigenvalue units)				
Total raw variance in observations =	-Empirical-	-Empirical-	-Empirical-	Modelled
Raw -scores variance in observations explained by both item and person measures =	50.9	100%		100%
Raw-scores variance in observations explained by Rasch persons abilities =	25.9	50.9%	← Expected values if these data fit the Rasch model → perfectly	46.5%
Raw-scores variance explained by Rasch item difficulties =	20.3	20.2%		18.5%
Unexplained variance by Rasch model	15.6	30.7%		28.0%
			←If these match reasonably, then the measures explain the expected amount→ of variance in the data	
Total raw unexplained by the Rasch model	25.0 count of items (or persons	49.1%	100%	53.5%
Unexplained variance in 1st contrast	4.9	9.1%	18.5%	
Unexplained variance in 2nd contrast	2.9	5.8%	11.8%	Simulate to estimate the Rasch-model expected values
Unexplained variance in 3rd contrast	2.3	4.5%	9.2%	
Unexplained variance in 4th contrast	1.7	3.4%	6.9%	
Unexplained variance in 5th contrast	1.6	3.2%	6.5%	

Note: 1st, 2nd, 3rd contrast etc. means the variance explained by contrast (another factor) which is unexplained by the Rasch model.

During data analysis, the teachers' scores from the developed TSPCK instrument were subjected to the Rash model and a scree plot of variance of items generated by the model is displayed in Fig. xxx below.

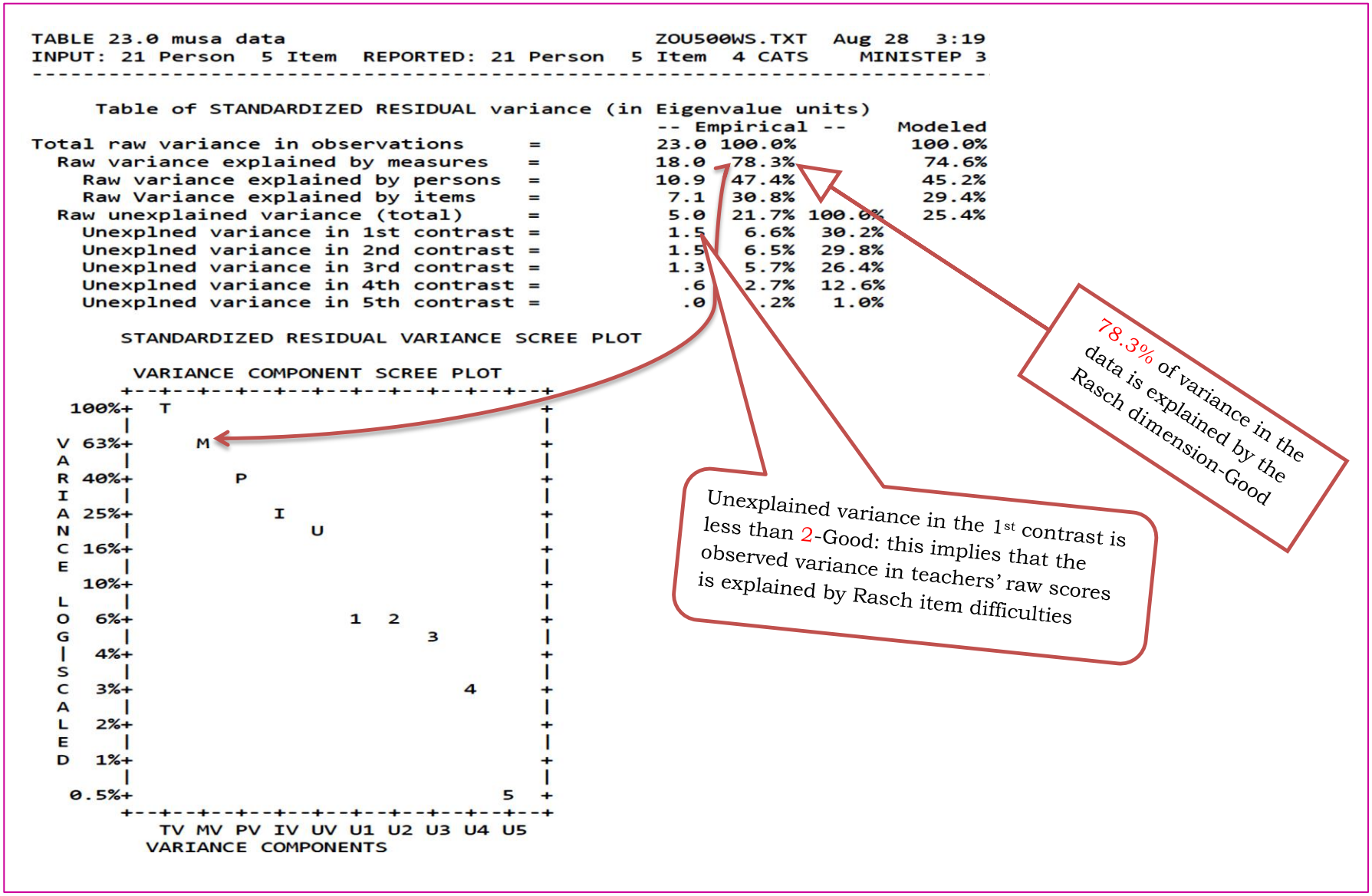


Figure xxx: Scree plot of variance of test items

Table xxxi shows the various components of the scree plot and their meaning (adapted from Linacre, 2012).

KEY		Explanation
T	TV	This is total variance in the observations. This is equal 100%
M	MV	This is variance that is explained by the Rasch measures
I	IV	This is variance explained by the person abilities
U	UV	This is variance explained by the item difficulties
1	U1	1st contrast in the residuals
2	U2	2nd contrast(component)

From figure xxx, it can be concluded that the designed TSPCK instrument is valid as shown by the amount of variance explained by items that fits perfectly with empirical evidence. Also displayed in Fig. xxx is that 30.8% of variance in the data is explained by items in the instrument and this value is close to the critical limit of 30.7%. (Refer to the Table xxx below for tentative guidelines). This is in line Linacre (2012) who argued that for the instrument to fit the Rasch model perfectly, the empirical values should always be approximately closed to the one predicted by the Rasch model. (The column labelled 'Model' in Fig. xxx). This is the case with my data. For example, in my study, the empirical value for items is 30.8% and that of the model is 29.4%. This further confirms the validity of the developed TSPCK instrument. The two variables in the study were the test items and persons abilities. From the scree plot, it can be seen that the 1st and 2nd contrast polled equally (1.5 eigenvalue units) which is <2, this shows that the observed variation in teachers' raw scores is explained by both test items and person abilities. Therefore, the data is compatible with the Rasch model since about 78% of variance is explained by measures: - a further evidence of the validity of the instrument.

.

Appendix A16: Linear regression statistics

A regression analysis output to show how much variance in the teachers' TSPCK scores is explained by CK

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.765466[a]
R Square	0.585938
Adjusted R Square	0.564145
Standard Error	2.46126
Observations	21

Good correlation co-efficient

About 59% of variance in teachers' TSPCK scores is explained by CK

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	1	162.8751	162.8751	26.88684	5.27E-05[b]
Residual	19	115.0982	6.057799		
Total	20	277.9733			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99.0%*	*Upper 99.0%*
Intercept	-4.22318	0.742	-5.69162	1.74E-05	-5.77621	-2.67016	-6.346	-2.10037
CK	1.797125	0.346584	5.185252	5.27E-05	1.071717	2.522534	0.805571	2.78868

a, b. predictor: (Constant), CK

Appendix A17: Extract of electrochemisrty content from Grade 12 NCS

1. EXTRACT FROM EXAMINATION GUIDELINE, 2009

Electrochemical reactions	
Electrolytic and galvanic cells	• Define the galvanic cell in terms of: o Self sustaining electrode reactions o Conversion of chemical energy to electrical energy • Define the electrolytic cell in terms of: o Electrode reactions that are sustained by a supply of electrical energy o Conversion of electrical energy into chemical energy • Define oxidation and reduction in terms of electron (e-) transfer/oxidation numbers. • Define anode and cathode in terms of oxidation and reduction. • Define oxidising and reducing agents in terms of electron transfer/oxidation numbers.
Relation of current and potential to rate and equilibrium	• Give and explain the relationship between current in an electrochemical cell and the rate of the reaction. • State that the pd of the cell (V_{cell}) is related to the extent to which the spontaneous cell reaction has reached equilibrium. • State and use the qualitative relationship between V_{cell} and the concentration of product ions and reactant ions for the spontaneous reaction viz. V_{cell} decreases as the concentration of product ions increases and the concentration of reactant ions decreases until equilibrium is reached at which the $V_{cell} = 0$ (the cell is 'flat'). (qualitative treatment only - exclude Nernst equation)
Understanding of the processes and redox reactions taking place in cells	• Describe: o movement of ions through the solutions o electron flow in the external circuit of the cell o the half reactions at the electrodes o function of the salt bridge in galvanic cells • Use cell notation or diagrams to represent a galvanic cell
Standard electrode potentials	• Give the standard conditions under which standard electrode potentials are determined. • Describe the standard hydrogen electrode o Explain its role as the reference electrode • Explain how standard electrode potentials can be determined using the reference electrode and state the convention regarding positive and negative values. • Use the Table of Standard Reduction Potentials to calculate the emf of a standard galvanic cell. • Use a positive value of the standard emf as an indication that the reaction is spontaneous under standard conditions.
Writing of equations representing oxidation and reduction half reactions and redox reactions	• Predict the half-cell in which oxidation will take place when connected to another half-cell. • Predict the half-cell in which reduction will take place when connected to another half-cell. • Write equations for reactions taking place at the anode and cathode. • Deduce the overall cell reaction by combining two half-reactions. • Describe, using half equations and the equation for the overall cell reaction, the following electrolytic processes: o The decomposition of copper chloride o A simple example of electroplating (e.g. the refining of copper) • Describe, using half equations and the equation for the overall cell reaction, the layout of the particular cell using a schematic diagram and potential risks to the environment of the following electrolytic processes used industrially: o Production of chlorine (see Gr 12 chem systems: chloroalkali industry). o Recovery of Al metal from bauxite. (South Africa uses Australian bauxite.)

2. NOTES FOR TEACHERS

Knowledge Area	Theme	Marks
Chemical Change (±50%)	• Energy & chemical change Grade 11 • Rate and extent of reaction **Electrochemical reactions** • Integrate the quantitative aspects of chemical change • Energy changes in reactions related to bond energy changes • Exothermic and endothermic reactions	**± 75 (total)**
Chemical Systems (±17%)	**Chloralkali industry** • Fertiliser industry **Batteries**	**±25 (total)**
	TOTAL	**150**

Displayed above is the total weighting of electrochemistry related content in the final chemistry paper 2 in the grade 12 NSC examination. About 40% of marks in the chemistry paper are examining the knowledge and application of concepts related to electrochemistry. The examination guideline is a guideline of electrochemistry concept that should be emphasized on by physical science teachers during their instruction.