The Teaching of Electrolytic Cell and its Fundamental Concepts: The Case of a Spiral Curriculum

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ABSTRACT

The research explored in-service teachers' classroom practices in teaching for conceptual understanding with a particular focus on the topic of Chemical Change. The topic is taught at different levels in the FET, being Reactions in aqueous solution at Grade 10; Redox reactions at Grade 11; and Electrolytic cell at Grade 12. The study was inspired by continual reports of South African Grade 12 learners' failure to adequately answer examination questions that demand a conceptual understanding of scientific knowledge on the topic Chemical Change. The study aimed to understand current teaching and learning processes in real life classrooms as well as to evaluate the spiral nature of the Physical Science curriculum. Special focus was on how Physical Sciences teachers' teaching approaches foster meaningful learning to enable learner conceptual understanding and access to scientific content. Physical Science curriculum documents were scrutinised for features of a spiral curriculum. The study followed an explanatory interpretative qualitative research paradigm with a case study methodology. The five participating in-service teachers, teaching a total of six classes were drawn from five different schools in three different districts of Gauteng province. Eighteen lessons were audio and video recorded, three lessons from each class and five teacher interviews we done. Scott, Mortimer and Aguiar's model of pedagogical link-making (PLM) was used to analyse the lessons. PLM comprises three aspects, link making to support continuity, link making to support knowledge building and link making to promote emotional engagement. Pedagogical link-making to support continuity was used both to analyse the spiral nature of the Physical Science curriculum and to analyse how the teachers sequenced the scientific concepts during the teaching and learning process. Pedagogical link making to support knowledge building was used to evaluate how teachers used the five pedagogical teaching tools that enable learners to actively construct knowledge. The Physical Science curriculum was found to be limited in its claims to a spiral nature at least for the topic Chemical Change and its essential concepts from Grade 10 to 12. Fundamental concepts such as Oxidation numbers (Grade 10) and Electrolytes (Grade 11) were not included in the curriculum in the respective grades. The lesson presentations by the teachers showed challenges in macro and meso link-making especially in the introductory lessons which hampered continuity from related past and future chemistry topics. Link-making at the micro level was well executed by all participants while the use of meso link-making increased from the first lesson to the third lesson. As far as link-making for knowledge building is concerned, I found that four of the five teachers used integration more than differentiation between everyday ways and scientific ways of explaining. Also, the use of both integration and differentiation increased from Grade 10 to 12. Two findings emerged with respect to making links between scientific concepts. Firstly, teachers generally illustrated the links between connected concepts very well. However, the second finding was that teachers seldom involved their learners in the linking of scientific concepts. In other words, teachers tended to retain authority in terms of conceptual engagement thus, compromising learning of conceptual understanding. There was hardly any link-making between scientific explanations and real-world phenomena with only one out of five teachers managing this. In terms of modes of representation, teachers successfully got learners to use multiple modes of representation. Finally, there was variation in how teachers moved between different scales and levels of explanation within a continuum in the way the triangle of levels of thought was used by the participants. On the one extreme of the continuum, all 3 levels of explanation were used by both teachers and learners while on the other teachers only used one level of explanation, either the macroscopic or symbolic. For meaningful learning to be a reality in science classrooms, the findings of my study suggest a need for both in-service and pre-service teachers to be introduced to approaches that promote conceptual understanding. The findings of this study recommend that the policy-makers consider the revision of the topic Chemical Change and align it to the features of a spiral curriculum.

Keywords

Pedagogical link-making, knowledge building, continuity, coherence, meaningful learning, conceptual understanding, the triangle of levels of thought, spiral curriculum.

DECLARATION

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

22nd day of May 2019

DEDICATION

I dedicate this thesis to my lovely wife, Sipiwe Mudadigwa, for your encouragement, love, support and understanding.

To my sons, Agape Prince and Elnathan Tonderai, for your understanding tolerance of my absence from home.

To my parents, Fibion and Norah Mudadigwa and my siblings (Elton, Ester, Beatrice, Priscilla, Sarah & Portia), for your love, support and prayers. Nhasi tinoti Ebenezer, Mwari watisvita pano nekuda kwenyasha dzake, Ndinotenda neminyeketero yenyu. Mwari wekudenga akupei makore mazhinji ekurarama.

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ABBREVIATIONS

AJRMSTE	African Journal of Research in Mathematics, Science and Technology Education
C2005	Curriculum 2005
CAPS	Curriculum Assessment Policy Statement
DA	Developmental Appraisal
DBE	Department of Basic Education
FET	Further Educational Training
GDE	Gauteng Department of Education
IQMS	Integrated Quality Management System
KB	Knowledge Building
PLM	Pedagogical Link Making
PM	Performance Measurement
PS	Performance Standard
NCS	National Curriculum Statement
SA	South Africa
STS	Science Technology and Society
TIMSS	Third International Mathematics and Science Study
WSE	Whole School Evaluation

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CHAPTER 1

Introduction to the study

1.0 Introduction

In this chapter, I introduce myself. I then relate a bit of my educational background for the reader to be acquainted with where I am coming from. In the process, I will make known the reasons why I have chosen the path my research has taken.

I attended my primary school in a rural village in the Chibi district of Masvingo province in Zimbabwe. I did my secondary education at a Dutch mission school in the same district. Being at a mission school meant that you had passed exceptionally well the Grade 7 examinations. Everyone at the boarding school was determined to work and study hard to achieve better results at both ordinary and advanced levels. The prominent form of teaching we were exposed to was that of listening and taking down notes or relying much on textbooks.

As learners, we evaluated our teachers' performances by the way they would come into the class and relate their subject matter in good and proficient English. We would go and then do our reading from textbooks and tried to comprehend everything on our own. We would form study groups where we explained to each other concepts that would be difficult for individuals to understand. As we studied, we verified if the teacher's knowledge complemented textbook knowledge. We showered those teachers who taught according to what we found in the textbooks with all proper names associated with good teaching.

I remember my Form two Agriculture teacher who had a masters' degree in that subject from Russia. He used to come to class with his head tilted to the left side of his head. He would give an oration of the day's work, explaining everything and writing notes on the board without textboard but direct from his head. As learners, we would write notes and develop our shorthand writing skills to catch up with the teacher's speed and talk. The bell saved us from writing notes, and the teacher would then leave the classroom with his head tilted to the right. We would later say, he has emptied his content knowledge on us, he became the yardstick of a good teacher to us.

In form 3, I encountered a Physical Science teacher whom we labelled lazy and not well educated who relied on us to get answers. He only had a diploma in Science Education and did not teach the way we had been taught in lower forms. He always grouped and encouraged us to discuss the day's work from work cards, and then gave a report back to the whole class. Learners with correct homework answers were asked to demonstrate to the class on the chalkboard, and he only interjected where necessary. We labelled him a lazy teacher, who came unprepared to class. I remember learners asking for a change of a teacher during form four but to no avail. In my later years at a Teachers' College, I learnt that the approach of my form three and four Physical Science teacher was one of the most encouraged teaching approaches. In contrast to our own belief that a good teacher was one who would have a degree and would not rely entirely on a textbook to teach. In our understanding, a good teacher was not supposed to ask questions but would transfer what he/she knows to us, and we would try to make sense of his/her oration on our own.

I completed my Advanced Level at the same mission school and later enrolled at a teachers' college. At the college, I learnt various teaching approaches and what my friends and I used to label the best teaching approach was vehemently discouraged. After graduating from a teachers' college, I was deployed in a rural secondary school where I found myself failing to implement those recommended teaching approaches. Instead, I reverted to the transmission method because it was the most straightforward method regarding preparation and classroom delivery. I registered at the University of Zimbabwe for my Bachelor of Education in Chemistry to increase my subject content knowledge. The aim of enrolling at the university had nothing to do with upgrading my teaching approaches but to be able to teach advanced level learners, the highest level of secondary education in Zimbabwe.

After my degree qualification, I taught Advanced Level Chemistry at a Christian mission school, where I continued with the transmission method. I would do anything for the learners, and I would ask them to reproduce what I had given them. My duty was to be sure of my subject matter as I go into the classroom, where I would give a spectacle performance of my Chemistry content knowledge. The learners showered me with praises of being a knowledgeable teacher the same way we did to our Agriculture teacher and others in my high school days.

The learners passed the same way we did because, at most mission schools, learners studied day and night and failing was not an option. Failing meant that the student would have to go to a secondary school called ‘upper tops’ in rural areas. School fees were very high at mission schools, and learners who were not coping with schoolwork were constantly reminded that if they fail their parents would lose much money. Being at a boarding school was so prestigious then, and most people would not want to lose that opportunity; hence, they worked hard to pass. Therefore, our teaching approaches would not be entirely associated with learner pass rate because there were other external factors to learners’ passing.

The economic meltdown in Zimbabwe forced me to cross the South African border for greener pastures in 2006. The environment was different, and learners of the two countries were not even comparable in my own perception. I used to intimidate learners in Zimbabwe about failing and going to lower prestigious secondary schools like ‘upper tops’ (secondary schools in rural areas). But that tactic did not work with South African learners as their parents would afford those high fees and learners will fail and repeat a grade at the same school. There was a need now to motivate learners for them to see the value of education. Employing the transmission method was not an option anymore as half of the class would be sleeping or engaging in disruptive behaviour. The transmission method gave me problems in classroom management, although I could cover a lot of content using the approach. But it meant that I moved with a very small fraction of the class. The rest of the learners would lag behind from the learning process. That is when I needed those teaching approaches, which I learnt in my years at college and the university.

To be relevant to the South African school education, I decided to enrol at a local university for my Honours degree in Physical Science education, and I went on to do a Masters' degree in Science Education. This was for me to upgrade myself academically and to learn more about the South African curriculum and current teaching approaches. That is when I learnt about the importance of the correlation of subject matter knowledge and the pedagogical knowledge in the teaching and learning process. The process of furthering my education in South Africa exposed me to different approaches that supported meaningful learning through learner conceptual understanding. My thesis is about teaching learners for conceptual understanding, and in the section that follows the rationale of my research is presented.

1.1 Rational

This study explores the nature of teaching strategies that are used by in-service teachers and whether their approaches encourage scientific conceptual understanding, through meaningful engagement in the teaching of Chemical Change at Further Educational Training (FET) phase in South Africa. Meaningful involvement in the classroom is vital for learners' understanding of scientific concepts. To achieve this goal, teachers should plan lessons that show the interrelatedness of concepts and employ strategies that encourage meaning-making. One of the approaches with such features is Pedagogical Link-Making (PLM) as advocated by Scott, Mortimer, and Ametller (2011). These scholars argue that this approach is fundamental to the teaching and learning of scientific knowledge. (Scott et al., 2011) describe PLM as a teaching and learning process where teachers and learners interlink concepts in a constant meaning making progression and knowledge building in classroom interactions.

PLM approaches consist of three primary forms which are pedagogical link-making to support knowledge building (KB), pedagogical link-making to promote continuity (PC) and pedagogical link making to encourage emotional engagement (EE). The detailed description of these forms will be covered in Chapter two which presents the literature review of this study. It is vital to note that the Department of Basic Education (DBE) through the Physical Science content document under Curriculum Assessment Policy Statement (CAPS) and the Integrated Quality Management System (IQMS) encourages teachers to use link-making and meaningful engagement in their teaching strategies.

CAPS is the latest version of the South African revised curriculum introduced in 2012 by DBE. IQMS is an instrument used in education to assess compliance with the curriculum policy by teachers and schools.

The Physical Science content document is a CAPS syllabus that contains the layout of concepts to be taught from Grade 10 to 12. The Physical Science content document advocates a spiral approach. The approach allows learners to construct an understanding of the concepts gradually over a period of time (Department of Education, 2006). This means, an idea is introduced in lower grades and is gradually built upon in successive higher grades. This is what Pedagogical Link-Making (PLM) to support knowledge building entails for making links between scientific concepts. Scott et al. (2011) argue that learning scientific conceptual knowledge encompasses the identification of how scientific ideas themselves fit together in an interweaving system. The science concepts are linked from one grade to the other as well as from one topic to the other, which the Department of Education refers to as conceptual progression and conceptual coherence respectively (Department of Education, 2006, 2011) Conceptual progression and coherence are equivalent to pedagogical link-making to promote continuity. The PLM to PC involves making connections between teaching and learning events separated in time (Scott et al., 2011). PLM to EE demands that the teacher cultivates a conducive emotional environment that keeps learners motivated during the teaching and learning process.

The DBE promotes this form of link-making in the IQMS document when it encourages teachers to have well established emotional quotient and to provide a supportive environment for learning. The questions that arise are: do in-service teachers practice these facets of knowledge building and conceptual understanding in the teaching and learning process of the Physical Science content knowledge? What constraints do teachers face in their quest to teach for conceptual understanding in the science classroom? My study focuses on the teaching of electrolytic cells and its fundamental concepts under Chemical Change, at the secondary school level. These are the questions that this thesis seeks out to address and reasons, if any, for why meaningful learning is difficult to achieve in South African science classrooms.

1.2 South African Context

Since South Africa gained its independence in 1994, there has been a quest by the democratically elected government to improve the education of the black South Africans, who were previously disadvantaged. This is evident in the government’s efforts to correct the educational system that was administered along racial lines where blacks were much ostracised. In 1997, the Outcomes-Based Education (OBE) curriculum was introduced to overcome the curricular barriers of the past, but the problems experienced in implementation prompted a review in 2000 (Jansen, 2002). This led to the first curriculum amendment: the *Revised National Curriculum Statement* (RNCS) *Grades R-9* and the *National Curriculum Statement* (NCS) *Grades 10-12* (2002) and was implemented in 2006 (Dada et al., 2009). Implementation challenges and the need to refine the curriculum resulted in the RNCS and the NCS in 2009 to yield the *National Curriculum Statement for Grades R-12* better known as the Curriculum and Assessment Policy Statements (CAPS). The CAPS was implemented in 2012, and the 2014 cohort was the first to write its National examination (Department of Education, 2011). The policy statement comprises of: (a) Curriculum and Assessment Policy Statements (CAPS) for all approved subjects itemised in this document; (b) National policy pertaining to the programme and promotion requirements of the National Curriculum Statement (NCS) *Grades R-12*; and (c) National Protocol for Assessment *Grades R-12* (Department of Education, 2011).

The methodological approaches advocated in the CAPS document, IQMS, NCS and the Physical Science Content document fit well into the pedagogical link-making approach postulated by (Scott et al., 2011). The Physical Science content document advocates a Spiral approach in science, which allows learners to gradually construct an understanding of the concepts over a period of time (Department of Education, 2006). The content document is structured in such a way that an idea is introduced in one grade and then revisited in the later grades and teachers must be able to link these concepts for the conceptual understanding of the entire concepts by the learner. This is what PLM to support KB entails under making links between scientific concepts. Scott et al. (2011) argue that learning scientific conceptual knowledge encompasses the identification of how scientific ideas themselves fit together in an interlinking system. The science concepts are linked from one grade to the other as well as from one topic to the other, which the DBE refers to as conceptual progression and conceptual coherence respectively (Department of Education, 2006, 2011).

The content document goes on to show teachers how science concepts are interlinked between the grades for all the topics in all grades (see Table 1.1) for the extract Knowledge Area (KA) Chemical Change.

Table 1.1: Progression of Chemical Change from Grade 10 to 12

Topic	Content	
Chemical Change	Grade 10	**Physical and chemical change** (separation by physical means; separation by chemical means; conservation of atoms and mass; the law of constant composition). **Representing chemical change** (balanced chemical equations). **Reactions in aqueous solution** (ions in aqueous solutions; ion interaction; electrolytes; conductivity; precipitation; chemical reaction types) **Stoichiometry (**mole concept**). 20 hours**
	Grade 11	**Stoichiometry** (molar volume of gases; concentration; limiting reagents; volume relationships in gaseous reactions) **Energy and chemical change** (energy changes related to bond energy; exothermic and endothermic reactions; activation energy). **Types of reactions** (acid-base; redox reactions; oxidation numbers) **28 hours**
	Grade 12	**Reaction rate** (factors affecting rate; measuring rate; mechanism of reaction and of catalysis). **Chemical equilibrium** (factors affecting equilibrium; equilibrium constant; application of equilibrium principles). **Acids and bases** (reactions; titrations, pH, salt hydrolysis). **Electrochemical reactions** (electrolytic and galvanic cells; the relation of current and potential to rate and equilibrium; standard electrode potentials; oxidation and reduction half-reaction and cell reactions; oxidation numbers; application of redox reactions). **28 hours**

The Department of Education (2006) asserts that when these links are shown to learners, they will appreciate the powerfulness of Physical Science in understanding the world. Pedagogical link-making has its roots in social constructivism. The pioneer of social constructivism, Vygotsky, argues that learners should not only be shown the links but must be involved in the identification processes of the links on a social plane (classroom discussions) for the internalisation that leads to a conceptual understanding of scientific concepts (Vygotsky, 1978).

By emphasising conceptual progression, the DBE fosters the idea of building new concepts on previous knowledge that is in line with educational research that learners are not blank slates. Driver, Asoko, Leach, Scott, and Mortimer (1994) in their pedagogical link-making approach, argue that understanding of new ideas involves making links between new ideas with already known and existing ideas.

Conceptual coherence can be attributed to pedagogical link-making to promote continuity through the scientific story development in *meso* scale (between lessons) and in the *micro* scale (within the lesson) (Scott et al., 2011). The CAPS content document acknowledges the use of representations for scientific conceptual knowledge such as graphs, equations, and vector arrows. This approach is in line with Scott et al. (2011) observation that an ability to make links between modes of representation makes a learner develops a deep understanding of scientific concepts.

In pedagogical link making to support knowledge building: moving between scales and levels of explanation has three levels that are important to conceptual understanding. These are macroscopic, sub-microscopic, and symbolic (Scott et al., 2011). The learners should be able to move between the three scales of representation to show an understanding of scientific concepts. The Physical Science content document (Department of Education, 2006) agree with Davidowitz, Chittleborough, and Murray (2010) and Johnstone (1991) that it is difficult to manage or understand all at once the macro, micro and symbolic levels for the description of chemical phenomena. The DBE asserts that "it is indeed inherently difficulty to think and comprehend in all the three ways at the same time" (Department of Education, 2006, p. 13). The DBE further argues that giving consistent attention to the three levels of representation right from Grade 10 will develop learners' conceptual scientific knowledge. The DBE uses an instrument called the Integrated Quality Management System (IQMS) to assess compliance with the curriculum policy by teachers and schools.

The IQMS consists of three main programmes, namely, Developmental Appraisal (DA); Performance Measurement (PM) and Whole School Evaluation (WSE). DA focuses on individual teacher appraisal to identify areas of strength and weaknesses to draw up programmes for teacher development in a transparent manner. PM aims to evaluate individual teachers mainly for salary progression as well as an affirmation of appointments, rewards, and incentives. The purpose of the WSE is to assess overall school effectiveness and the quality of teaching and learning processes (Department of Education, 2009). How the instrument is implemented in schools is beyond the scope of my research, but I hasten to say that in my experience at my school. DA was not of importance, teachers only focused on the PM as it relates to salary progression. The purpose of acknowledging this instrument is to show the reader how the instrument complements the pedagogical link-making.

In PM, there is a 52-page document which is used to identify strengths and weaknesses of the teachers as well as to rate them on a continuum of scores from 1 to four where rating score of 1 is weak, and four denotes strength. An extract of one of the performance standards is shown in Table 1.2 below. I have highlighted points that can be related to pedagogical link-making (Department of Education, 2009).

Table 1.2: Performance Standard One: Creation of a Positive Learning Environment

CRITERIA	SCORE 1	SCORE 2	SCORE 3	SCORE 4
Learner involvement **[b]**	**Educator and learners appear uninterested** **Performance indicators** ✓ Learners and educators appear disinterested ✓ Lecture type lesson with no learner involvement ✓ Learners often engaged in activities not related to the lesson ✓ General learner apathy in classroom ✓ Learners are often engaged in self-study exercises without any guidance from educator ✓ Educator displays prejudice towards some learners	**Learners are engaged in appropriate activities for most of the lesson.** Performance indicators ✓ Learners attention is gained by the educator ✓ Lesson is interspersed with questions that allows for learner participation ✓ Learners are encouraged to communicate with educator and fellow learners ✓ Activities and tasks are varied to a limited degree ✓ Meaningful tasks are given to learners ✓ Educator makes concerted effort to create a positive learning environment ✓ Learners are guided in respect of tasks ✓ Educator creates a non-prejudicial atmosphere in classroom	**The environment is stimulating, and learners participate actively** Performance indicators ✓ Learners are lively and participate willingly ✓ Educators create a learning atmosphere which supports constant learner involvement ✓ Lesson is structured to allow for meaningful engagement ✓ Learners are encouraged to communicate freely ✓ Varying, meaningful tasks are given to learners and appropriate interventions are made by the educator ✓ Educator has a good emotional quotient and provides a very supportive environment for learning and risk taking ✓ Educator uses activities to foster creativity and imaginative thinking ✓ Educator fosters tolerance and a non-prejudicial atmosphere	**Learners participate actively and are encouraged to exchange ideas with confidence and be creative** Performance indicators ✓ Learners are lively participants and contribute to knowledge creation and acquisition ✓ Educator creates a learning environment that recognises the multiple intelligences of the learners ✓ Lesson is carefully structured to allow for meaningful engagement ✓ Learners communicate their ideas with confidence ✓ Educator has an extremely well developed emotional quotient and provides a very supportive environment for learning and risk taking ✓ Lesson is not resource bound and educator is able to improvise and be flexible ✓ Educator fosters tolerance and a non-prejudicial atmosphere

Each Performance Standard (PS) has four criteria labelled (a) to (d), and under each score, there are aspects which evaluators use to evaluate the teacher. In PS 1 [B] there are three highlighted aspects underscore 4 which can be linked to pedagogical link-making and social constructivism. The first point subscribes to both knowledge building and conceptual scientific knowledge. Point two speaks to fostering classroom discourse that perpetuates meaningful engagement, which can be provided for by learner interaction on the social plane. The emotional quotient in point three can be attributed to the third form of pedagogical link-making to encourage emotional engagement, whereby the teacher can engender a positive emotional response from the learners which generates a positive classroom environment (Scott et al., 2011). In the IQMS document, several performance standards can be shown to be in line with the pedagogical link-making, and these will be referred to as the research unfolds. These features of the South African CAPS curriculum are related to pedagogical link-making, which is the primary focus of this study.

1.3 Problem Statement

My concern with school science is for learners to comprehend science concepts as they are being taught in science classrooms. This will only occur if the teacher is competent in the subject matter and if the teaching is done through the selection and use of appropriate approaches to attain such scientific conceptual knowledge. Scott et al., (2011), notes that the teacher needs to be an expert in the subject matter for the successful implementation of teaching and learning processes for scientific conceptual knowledge.

Shulman (1986) argues that there should be an assumption that teachers begin with some expertise in the subject they teach especially at the secondary level. Teachers are expected to have completed a major in the subject of their specialisation. In the evaluation of teachers for the Developmental Appraisal (DA) and Performance Measurement (PM) underperformance standard two criteria [A]: emphasises that the educator is expected to possess an in-depth understanding of his/her learning area/subject and uses appropriate strategies to extend knowledge of the learners (Department of Education, 2009). Content must not be divorced from the teaching approaches, as the two complement each other. There is a great need for blending the teaching pedagogy with content knowledge, and there is no chance of compromising one from the other (Shulman, 1986).

In my introduction, I alluded to the Agriculture teacher who had a degree in his subject area but lacked appropriate teaching approaches. The teacher only amused learners with his discourse of the subject matter and left learners to memorise the intended concepts to be learned. There is a need to acquaint teachers with new and innovative teaching approaches that do not only prepare learners for examinations but foster scientific conceptual knowledge. The understanding of science concepts will also cause learners to be confident to take the science program at higher institutions. This could be one of several reasons why South African learners do not do well in Physical Science.

According to the Third International Mathematics and Science Study (TIMSS), which test the competency of learners in science and mathematics at Grades 4 and 8 after every four years since 1995 (Martin, Mullis, Foy, & Stanco, 2012), South Africa has not been doing well in science education. In the TIMSS assessment analysed in this research, South Africa participated in all the tests from 1995 to 2011 except 2007. In 2011, Botswana, Ghana and South Africa ".. administered the TIMSS 2011 assessment to Grade 9 learners as they found the assessment difficulty for the 8th grades" (Martin et al., 2012, p. 24). South Africa's results were always lower, or at the bottom, in the four years, they participated in the TIMSS assessment. (Harmon, Smith, Martin, Kelly, & Beaton, 1997; Martin et al., 2012; Martin et al., 2000; Mullis, Martin, Gonzalez, & Chrostowski, 2004). The results for the five years are summarised on the table below.

Table 1.3: Summary of the TIMSS Results Score with Special Emphasis on South Africa from 1999 to 2011

Year	No. of Participating Countries	International Average Score	Highest Average Score	SA Average Score	Lowest Average Score	SA Grade Tested	Average Age SA (Inter)
1995	26	518	580	236	263	8	
1999	38	521	569	243	243	8	15.5 (14.4)
2003	46	474	578	244	244	8	15.1 (14.5)
2007	57	500	567	-	303	-	
2011	59	500	590	332	332	9	16.0 (15.8)

In all the years, South Africa had the lowest score among the participating countries. As can be noted from Table 1.3, South Africa has the highest age average among participating countries. South African learners' performance is not comparable to most of the participating countries even though they were approximately a year older than other participants. Even in 2011 where only three countries participated with Grade 9 learners, South Africa had the highest age average (Botswana, 15.8; Honduras 15.7 & South Africa 16.0) (Martin et al., 2012). South Africa was lowest among countries where Grade 9 learners participated with an average score of 332 lower than Botswana (404) and Honduras (369), even though they have comparable year averages (Martin et al., 2012). The country that was lowest in the TIMSS 2011 among countries that tested Grade 8 was Ghana, which was also the lowest performing country (Average score of 303) in 2007 where South Africa did not participate. The poor performance of South African learners at an international level in Grade 8 or 9 science is clearly represented graphically in Figure 1.1 below.

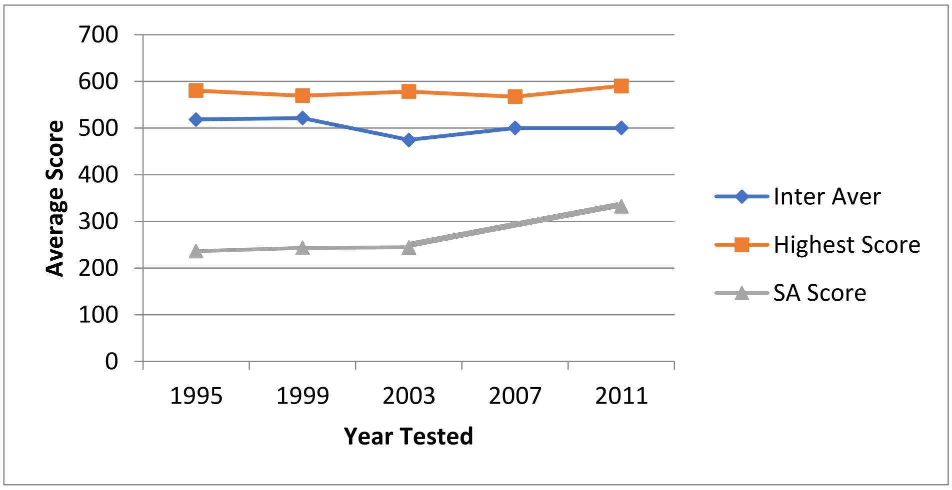


Figure 1.1: South Africa Average Score against International Average Score

The huge gap between the international average score and the South African average score in all the years South Africa participated in the TIMSS assessments is a cause of concern among academics. For example, Mji and Makgato (2006) and Kriek & Basson (2008) indicated that South African learners' mathematics and poor science performance in Africa and internationally painted a gloomy picture for the nation and was a cause of concern. This poor performance, especially in Physical Science, spills into the National Senior Certificate (NSC) examination, which is a high school exit examination. Kriek and Basson (2008) gave the poor performance at Grade 12 national examinations as the reason for low numbers of learners taking science related courses at university levels.

An analysis of the Physical Science NSC 2014 results and prior years since 2008 confirms that a lot needs to be done, especially in the teaching and learning of science subjects. The NCS 2014 pass rate was lower than the 2013 NCS results, nationally. The decrease has been attributed to the change in the curriculum by the Department of Basic Education because since 2008 the results were gradually improving, as indicated in the graph below.

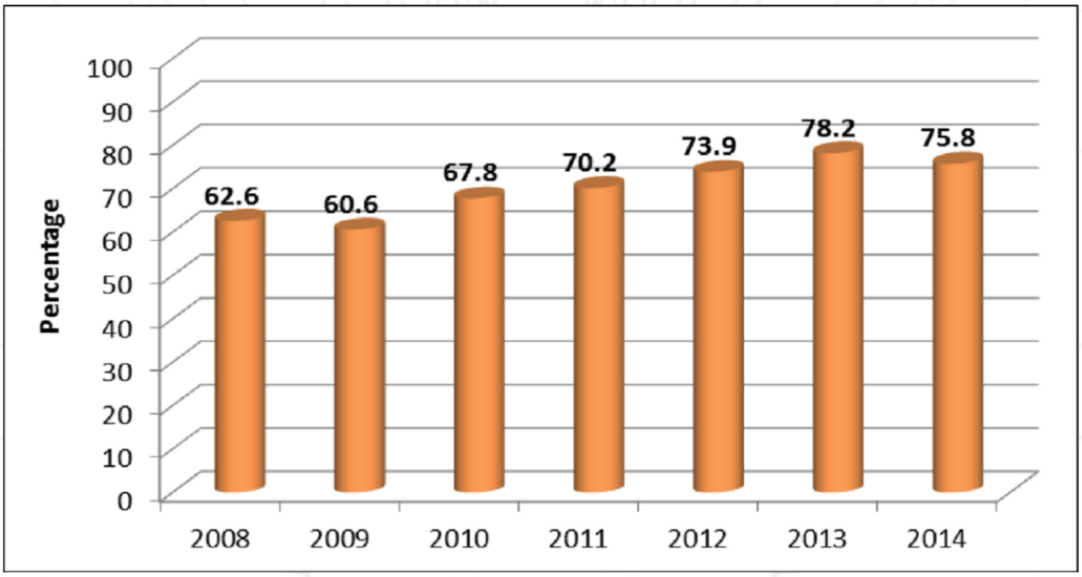
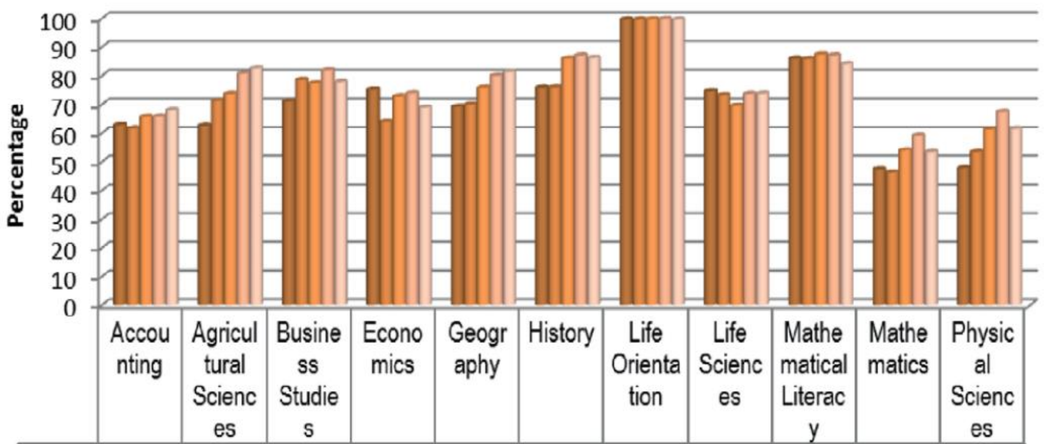


Figure 1.2: Comparison of NSC pass rate from 2008 to 2014 (Department of Education, 2014b)

This trend cascaded in almost subjects at the national level as indicated in Figure 1.3 below.

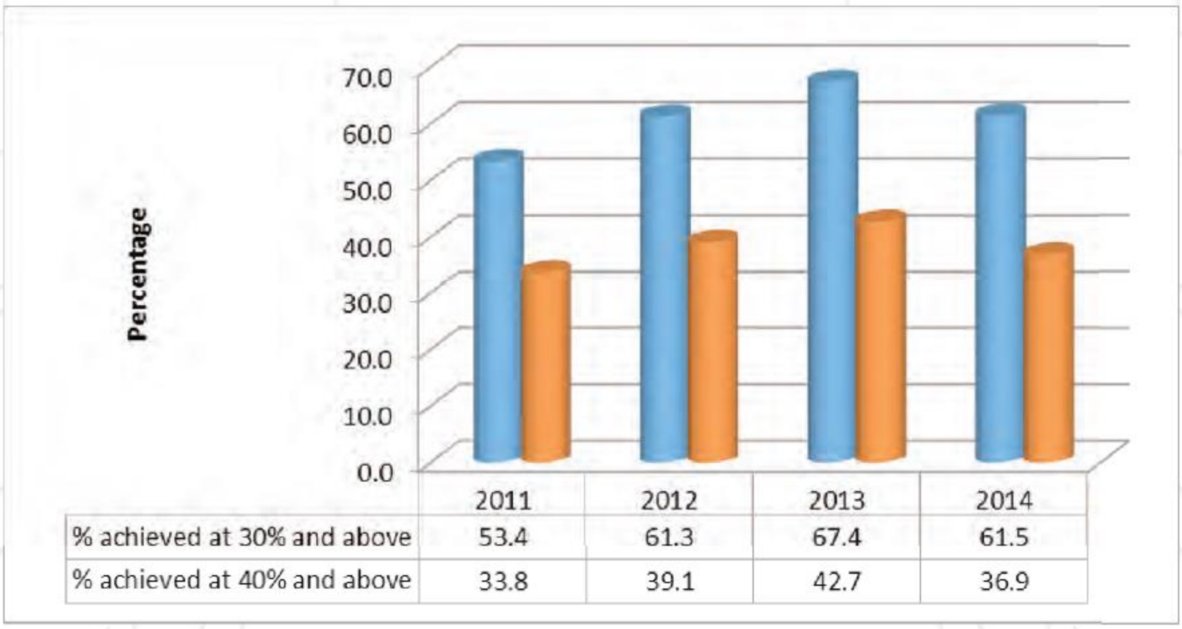


	Accounting	Agricultural Sciences	Business Studies	Economics	Geography	History	Life Orientation	Life Sciences	Mathematical Literacy	Mathematics	Physical Sciences
2010	62.8	62.6	71.1	75.2	69.2	75.8	99.6	74.6	86	47.4	47.8
2011	61.6	71.3	78.6	64	70	75.9	99.6	73.2	85.9	46.3	53.4
2012	65.6	73.7	77.4	72.8	75.8	86	99.7	69.5	87.4	54	61.3
2013	65.7	80.7	81.9	73.9	80	87.1	99.8	73.7	87.1	59.1	67.4
2014	68.0	82.6	77.9	68.9	81.3	86.3	99.6	73.8	84.1	53.5	61.5

Figure 1.3: Candidates' performance at 30% and above in selected subjects from 2010 to 2014 (Department of Education, 2014b)

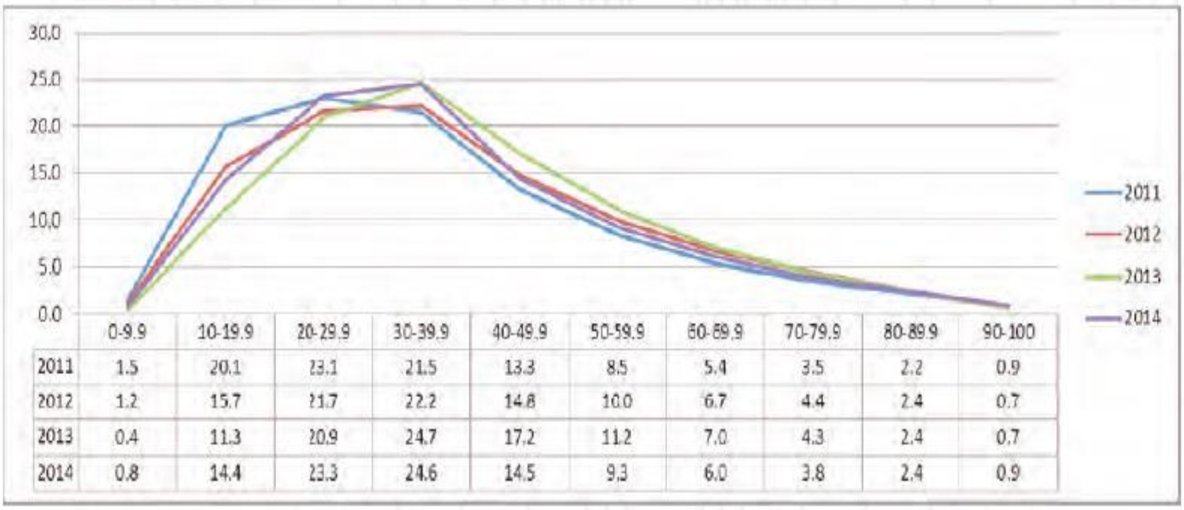
Mathematics and Physical Science in the graph above had a lower pass rate than other subjects indicated in the past five years. Focussing on Physical Science alone will give a clearer perception of how the learners perform in this subject particularly in the area of Chemical Change in chemistry.

It is of interest to note that the 2014 Physical Science Grade 12 cohort is the same cohort that wrote the 2011 TIMSS assessment when they were in Grade 9 and could not perform well. A comparison of the 2014 cohort with that of 2013 shows that the number of candidates who passed by 30% decreased by 5.9% points and those who passed by 40% decreased by 5.8% point (Department of Education, 2014a), as shown in Figures 1.4 and 1.5 below.



	2011	2012	2013	2014
% achieved at 30% and above	53.4	61.3	67.4	61.5
% achieved at 40% and above	33.8	39.1	42.7	36.9

Figure 1.4: Overall achievement in Physical Science from 2011 to 2014 (Department of Education, 2014b)



	0-9.9	10-19.9	20-29.9	30-39.9	40-49.9	50-59.9	60-69.9	70-79.9	80-89.9	90-100
2011	1.5	20.1	23.1	21.5	13.3	8.5	5.4	3.5	2.2	0.9
2012	1.2	15.7	21.7	22.2	14.8	10.0	6.7	4.4	2.4	0.7
2013	0.4	11.3	20.9	24.7	17.2	11.2	7.0	4.3	2.4	0.7
2014	0.8	14.4	23.3	24.6	14.5	9.3	6.0	3.8	2.4	0.9

Figure 1.5: Performance distribution curves in Physical Science from 2011 to 2014

The normal distribution curve shows that many of the learners in the past four years were between 20% and 39.9%. The general comments for NSC 2014 examination embedded in the diagnostic analysis of 2014 indicated that learners struggle extensively with questions that seek scientific explanations, as well as a general lack of understanding of basic concepts and conceptual interpretation (Department of Education, 2014b).

Physical Science comprises of two sections: the Physics section (paper 1) and the Chemistry section (paper 2). In Chemistry, learners are assessed in three learning areas; namely, Matter & Material, Chemical Change and Chemical Systems and there were 10 questions in the NSC 2014 examination. Table 1.4 below shows how learners performed per question per learning area.

Table 1.4: Average marks per question and per learning area for 2014

Question No.	Specific Topic	% Average Mark	Learning Area	% average Mark
1	Multiple Choice	52	Mixed	52.0
2	Organic Nomenclature	65	Matter and Material	57.7
3	Physical Properties organic compounds	47		
4	Organic reactions	61		
5	Reaction Rate	36	Chemical Change	40.6
6	Chemical Equilibrium	41		
7	Acids and Bases	48		
8	Galvanic Cells	45		
9	Electrolytic Cell	33		
10	Fertilisers	58	Chemical Systems	58.0

Inferences from Table 1.4 show that learners found the chemical change to be difficult as it has the lowest percentage average among the three learning areas. Table 1.5 shows the comparison of the learning areas in the past three years.

Table 1.5: Comparison of Average percentage mark in Chemistry learning areas from 2012 to 2014

	% average Mark		
Learning Area	**2012**	**2013**	**2014**
Mixed	64.1	41.4	52.0
Matter and Material	54.4	41.1	57.7
Chemical Change	43.8	27.9	40.6
Chemical Systems	46.1	25.3	58.0

In 2013 the average mark for Chemical Change and Chemical Systems learning areas were shallow than the other two years. In the diagnostic analysis of 2013, the Department of Education indicated that candidates performed poorly in paper 2. The Chemical Change questions were again a cause of concern in the 2013 NCS examination. The following reasons were given as the cause for the poor performance in the paper (Department of Education, 2013, p. 185);

- *Lack of skills to interpret data and to give reasons/explanations resulted in the very poor answering of the question on reaction rate (Q6).*
- *Stoichiometric calculations (Q6.6 & Q9.3) were poorly answered. Although most candidates could select the correct formula, they often failed to work with correct mole ratio.*
- *Q9 (electrolytic cells) was extremely poorly answered. Many candidates obtained zero for this question.*
- *Electrolytic cells remains a poorly understood section of the work.*
- *In general, candidates had a poor understanding of electrochemistry (Q8, Q9, Q10).*
- *The inability to answer questions like Q6.4, Q6.6, Q8.3, Q9.3 and Q10, which were somewhat "outside the box", although not difficult, is worrisome, as it points to a serious flaw in the thinking skills of candidates.*

The comments above were related to one learning area of Chemical Change. It should be noted that though the marks for 2014 look better than 2013, they are not the accurate reflection of the candidates' real performance. According to the North West MEC, Maphefo Matsemela, the Physical Science results were even worse than the statistics given as there was an upward adjustment of marks (Department of Education, 2015a). Below is the graphical comparison of the learning areas over the three years.

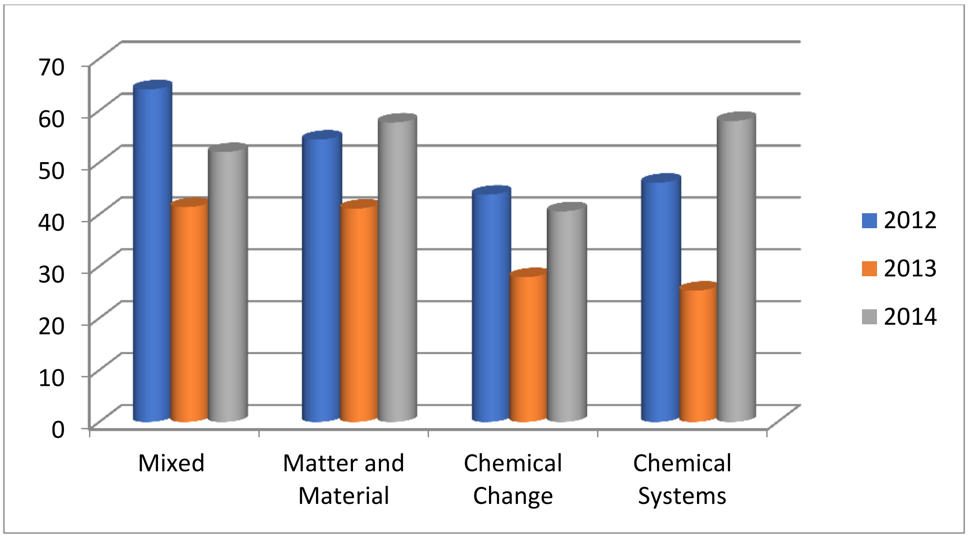


Figure 1.6: Graphical representations for the average percentage mark in Chemistry learning areas from 2012 to 2014

As can be depicted in the graph above the learning area of Chemical Change has been difficult for learners in the three years under consideration. Generally, the topic is the most failed among the three learning areas. Except in 2013, it was above the chemicals systems by 2.6 % points. This could be attributed to the concept of Batteries that also proved to be a difficult topic for the learners and was replaced by the concept of Acids and Bases in the revised CAPS curriculum. Table 1.6 below shows the analysis of average marks per question and per learning area for 2012 and 2013. Note that there were 11 questions in the previous curriculum.

Table 1.6: Average marks per question and per learning area for 2012 and 2013

<table>
<tr><td>Year</td><td colspan="2"></td><td colspan="2">2012</td><td colspan="2">2013</td></tr>
<tr><td>Question No.</td><td>Specific Topic</td><td>Learning Area</td><td>% Average Mark</td><td>% average Mark</td><td>% Average Mark</td><td>% average Mark</td></tr>
<tr><td>1</td><td>One Word Answers</td><td rowspan="2">Mixed</td><td>73.6</td><td rowspan="2">64.05</td><td>38.4</td><td rowspan="2">41.4</td></tr>
<tr><td>2</td><td>Multiple Choice</td><td>54.5</td><td>44.4</td></tr>
<tr><td>3</td><td>Organic Nomenclature</td><td rowspan="3">Matter and Material</td><td>60.5</td><td rowspan="3">54.37</td><td>40.4</td><td rowspan="3">41.1</td></tr>
<tr><td>4</td><td>Physical Properties organic compounds</td><td>58.1</td><td>45.8</td></tr>
<tr><td>5</td><td>Organic reactions</td><td>44.5</td><td>37</td></tr>
<tr><td>6</td><td>Reaction Rate</td><td rowspan="4">Chemical Change</td><td>33.2</td><td rowspan="4">43.80</td><td>23.7</td><td rowspan="4">27.9</td></tr>
<tr><td>7</td><td>Chemical Equilibrium</td><td>44.4</td><td>30.5</td></tr>
<tr><td>8</td><td>Galvanic Cells</td><td>53.8</td><td>29.4</td></tr>
<tr><td>9</td><td>Electrolytic Cell</td><td>45.6</td><td>17.2</td></tr>
<tr><td>10</td><td>Batteries</td><td rowspan="2">Chemical Systems</td><td>50</td><td rowspan="2">46.10</td><td>19.1</td><td rowspan="2">25.3</td></tr>
<tr><td>11</td><td>Fertilisers</td><td>42.2</td><td>31.5</td></tr>
</table>

The trend exhibited above dates back from the inception of the NCS curriculum in 2008.

In their study of first-year university chemistry students, who were the 2008 Grade cohort (the pioneers of NCS curriculum) Davidowitz et al. (2010) found out that topics like Reactions and Stoichiometry were poorly performed. By comparing the first-year student 2009 cohort with 2005 and 2007 cohorts, they found out that the 2009 cohort declined in conceptual knowledge and understanding. They observed that the decline was dramatic in acids and bases and in basic concepts such as Atoms and Ions, Mole Concept and Reactions (Davidowitz et al., 2010). The topic of Chemical Change is quite essential in the South African Chemistry curriculum because it contributes more marks to the final weighting of the second paper of the final exit examination at Grade 12. The topic carries a significant average of 47.6% point across the phase and the highest average percentage point of 56 at Grade 12. Table 1.7 shows these trends for Grade 10 to 12.

Table 1.7: Summative weighting of Chemistry Learning areas from Grade 10 to 12

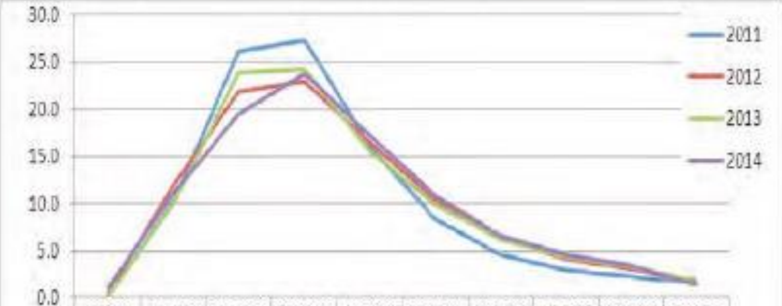
Grade	**Grade 10**		**Grade 11**		**Grade 12**		**Total Per Phase**	
Contribution	**Mark**	**%**	**Mark**	**%**	**Mark**	**%**	**Mark**	**%**
Matter and Material	70	46.7	60	40.0	48	32.0	178.0	39.556
Chemical Change	60	40.0	70	46.7	84	56.0	214.0	47.556
Chemical Systems	20	13.3	20	13.3	18	12.0	58.0	12.889
Total	150	100	150	100	150	100	450	100.001

The drop in the pass rate as alluded to before can be attributed to the introduction of the new curriculum the CAPS in 2012, and its first examination was written in 2014 (Department of Education, 2014a). In its report, the DBE has set three targets directed to the National Senior Certificate candidates,
and these are;

(a) Increase the number of Grade 12 learners who become eligible for a bachelor's Programme at a University;
(b) Increase the number of Grade 12 learners who pass Mathematics; and
(c) Increase the number of learners who pass Physical Science (Department of Education, 2014a).

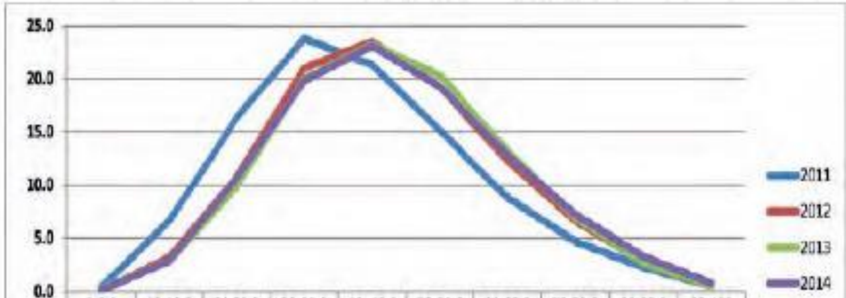
The first target focuses on the increase in learners that can be eligible for a bachelor's degree programme. The minimum requirement for a university bachelor's degree entry is four subjects with an achievement rating of 4 (Adequate achievement, 50% - 59%) and a minimum of 40% in the language of Instructions (Department of Education, 2014b). For this goal to be attained, the Department of Basic Education must increase its promotional achievement bar to 50% from Grade 10 for each subject. This is because learners from Grade 10 aim to achieve just above 30% for them to be promoted to the next grade. Most learners tend to work hard and to attain above 60% for science only in Grade 12 to be accepted in science-oriented programmes at universities. This observation is based on an analysis of the trend in normal distribution curves for eight selected subjects presented in the Diagnostic Report (Department of Education, 2014a). The peak of the normal distribution curves for most of the subjects is between 30% - 39% which indicates that many learners had attained achievement level two except in Home Language and History, from 2011 to 2014.

Graph 2.1.2 Performance distribution curves in Accounting



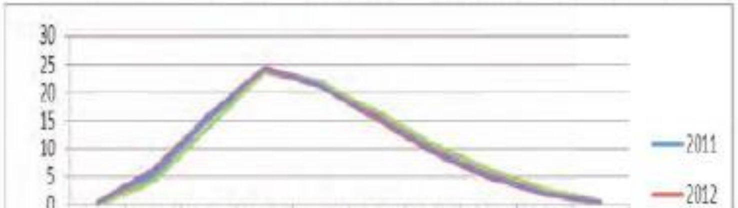
	0-9.9	10-19.9	20-29.9	30-39.9	40-49.9	50-59.9	60-69.9	70-79.9	80-89.9	90-100
2011	0.2	10.5	26.1	27.3	16.0	8.4	4.7	3.0	2.3	1.5
2012	0.6	12.1	21.8	22.9	16.5	10.5	6.6	4.2	3.1	1.8
2013	0.2	10.2	23.9	24.2	15.5	10.0	6.3	4.4	3.4	1.9
2014	1.2	11.3	19.5	23.7	17.1	11.0	6.7	4.6	3.5	1.4

Graph 8.1.2 Performance distribution curves in History (2011–2014)



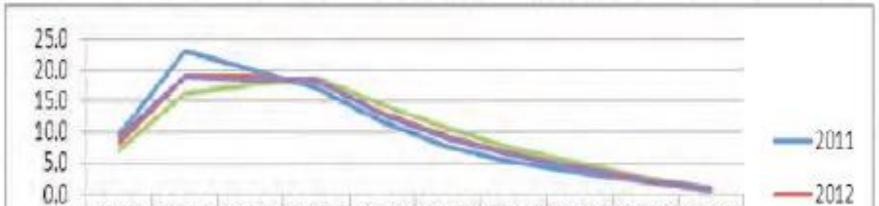
	0-9.9	10-19.9	20-20.9	30-39.9	40-49.9	50-59.9	60-69.9	70-79.9	80-89.9	90-100
2011	0.4	6.6	16.3	23.8	21.3	15.1	8.8	4.7	2.3	0.5
2012	0.1	3.2	10.7	21.0	23.5	19.2	12.3	6.6	2.8	0.7
2013	0.2	2.9	9.8	20.0	23.2	20.3	13.2	6.9	2.7	0.5
2014	0.1	2.9	10.6	19.8	23.1	19.2	12.8	7.2	3.3	0.8

Graph 4.2.1 Performance distribution curves in Business Studies



	0-9.9	10-19.9	20-29.9	30-39.9	40-49.9	50-59.9	60-69.9	70-79.9	80-89.9	90-100
2011	0.2	5.0	15.2	24.1	21.8	16.2	9.8	5.2	2.1	0.4
2012	0.3	6.3	16.0	24.4	21.3	15.2	9.2	4.8	2.0	0.4
2013	0.2	4.1	13.8	23.7	21.6	16.5	10.8	6.2	2.6	0.5
2014	0.3	6.1	15.8	24.1	21.2	15.6	9.5	5.0	2.1	0.4

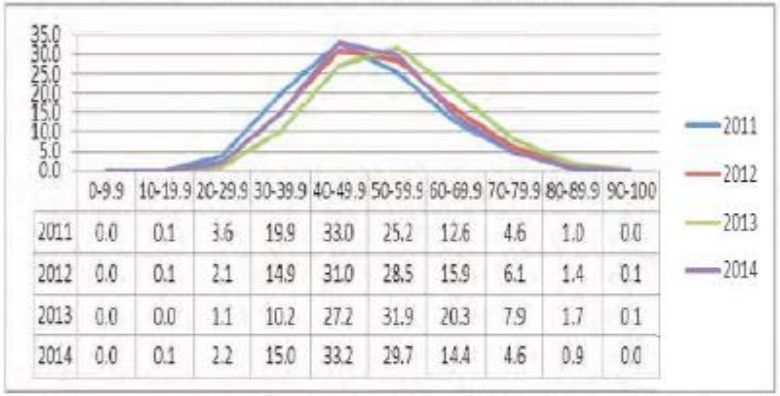
Graph 10.1.2 Performance distribution curves in Mathematics



	0-9.9	10-19.9	20-29.9	30-39.9	40-49.9	50-59.9	60-69.9	70-79.9	80-89.9	90-100
2011	9.5	23.1	20.0	17.2	11.6	7.6	5.1	3.4	1.9	0.6
2012	8.3	18.8	18.9	18.3	13.0	9.2	6.4	4.1	2.2	0.7
2013	7.1	16.2	17.6	18.6	14.3	10.5	7.4	4.8	2.6	0.8
2014	9.3	18.8	18.5	18.4	12.7	8.9	6.1	4.1	2.3	0.9

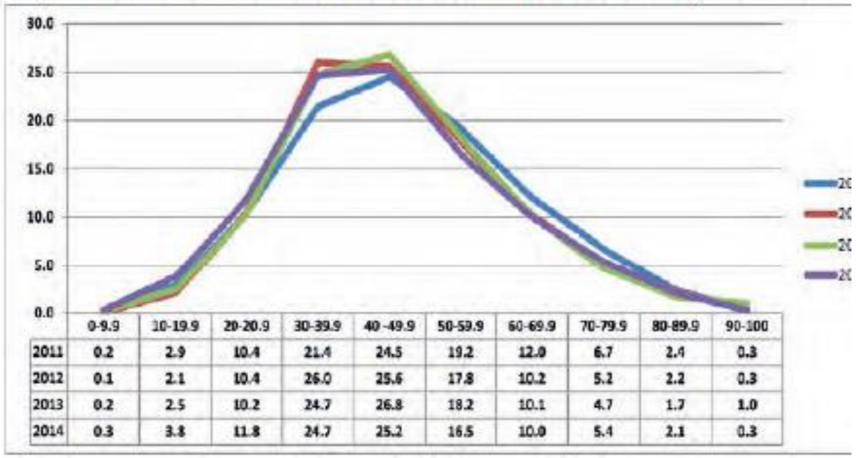
Figure 1.7: Normal distribution curves for the analysis of the eight subjects (Department of Education, 2014a)

Graph 6.1.2 Performance distribution curves for English First Additional Language



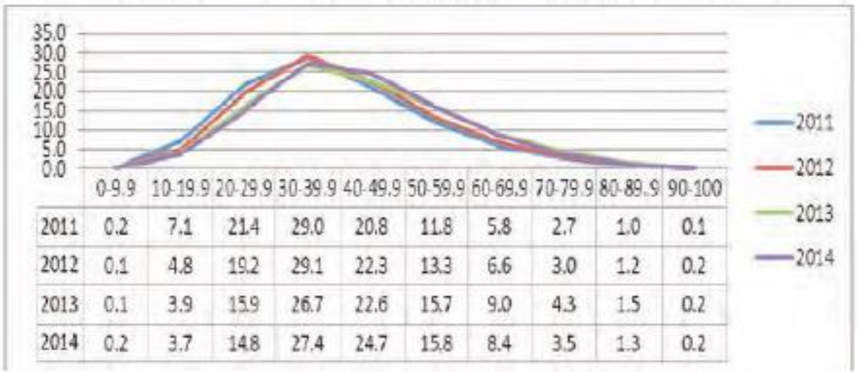
	0-9.9	10-19.9	20-29.9	30-39.9	40-49.9	50-59.9	60-69.9	70-79.9	80-89.9	90-100
2011	0.0	0.1	3.6	19.9	33.0	25.2	12.6	4.6	1.0	0.0
2012	0.0	0.1	2.1	14.9	31.0	28.5	15.9	6.1	1.4	0.1
2013	0.0	0.0	1.1	10.2	27.2	31.9	20.3	7.9	1.7	0.1
2014	0.0	0.1	2.2	15.0	33.2	29.7	14.4	4.6	0.9	0.0

Graph 11.1.2 Performance distribution curves in Mathematical Literacy



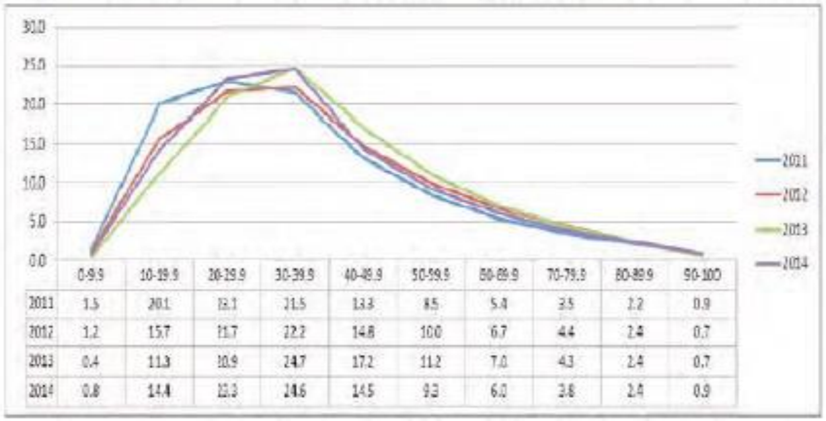
	0-9.9	10-19.9	20-20.9	30-39.9	40 -49.9	50-59.9	60-69.9	70-79.9	80-89.9	90-100
2011	0.2	2.9	10.4	21.4	24.5	19.2	12.0	6.7	2.4	0.3
2012	0.1	2.1	10.4	26.0	25.6	17.8	10.2	5.2	2.2	0.3
2013	0.2	2.5	10.2	24.7	26.8	18.2	10.1	4.7	1.7	1.0
2014	0.3	3.8	11.8	24.7	25.2	16.5	10.0	5.4	2.1	0.3

Graph 7.1.2 Performance distribution curves in Geography



	0-9.9	10-19.9	20-29.9	30-39.9	40-49.9	50-59.9	60-69.9	70-79.9	80-89.9	90-100
2011	0.2	7.1	21.4	29.0	20.8	11.8	5.8	2.7	1.0	0.1
2012	0.1	4.8	19.2	29.1	22.3	13.3	6.6	3.0	1.2	0.2
2013	0.1	3.9	15.9	26.7	22.6	15.7	9.0	4.3	1.5	0.2
2014	0.2	3.7	14.8	27.4	24.7	15.8	8.4	3.5	1.3	0.2

Graph 12.1.2 Performance distribution curves in Physical Sciences



	0-9.9	10-19.9	20-29.9	30-39.9	40-49.9	50-59.9	60-69.9	70-79.9	80-89.9	90-100
2011	1.5	20.1	22.1	21.5	13.3	8.5	5.4	3.5	2.2	0.9
2012	1.2	15.7	21.7	22.2	14.8	10.0	6.7	4.4	2.4	0.7
2013	0.4	11.3	20.9	24.7	17.2	11.2	7.0	4.3	2.4	0.7
2014	0.8	14.4	23.3	24.6	14.5	9.3	6.0	3.8	2.4	0.9

Figure 1.8: Normal distribution curves for the analysis of the eight subjects (Department of Education, 2014a)

It should be noted that the First Additional Language promotional pass requirement is 40% and above from Grade 10 to 12. Hence, most learners strive to attain this achievement pass level. There has been an outcry from several South African academics including Jonathan Jansen, a former Vice-Chancellor of the University of the Free State. Jonathan Jansen posits that the pass mark for all subjects must be increased to 50%, which is a benchmark pass of most countries (Sapa, 2014). It will be a mammoth task based on the analysis of results since 2011 for the Department of Basic Education (DBE) to push the peaks of normal distribution curves to the right by a 20% point on average for all other subjects and 10% point average for History and Home Language.

Nevertheless, the DBE acknowledges that there is a need to improve the quality of teaching and learning and states that;

> *Our teachers, school managers and subject advisors need to collectively focus on raising the quality of learning and teaching by being open to the measures used to identify where the problems are and how to correct them (Department of Education, 2014b, p. 26).*

The Minister of Basic Education in her national address on the day of the release of 2014 NCS results indicated that the pass percentage has been raised for Grade 12 and said that;

> *Following the recommendations made by the Ministerial committee on pass requirements, led by Professor Brian Cornwell in December, also announced that the pass mark for Grade 12 will be increased as part of our effort to continue to bring quality to our education will provide more details later* (Department of Education, 2015b)

The TIMSS investigated the possible factors affecting the science education results of the learners in the participating countries. Among the factors that were noted were school resources for teaching science, home environment support for science achievement, teacher preparation, school climate and classroom instruction. Concerning classroom instruction, TIMSS 2011 reported that countries in which teachers used instruction that engaged learners in the science classroom scored highly (Martin et al., 2012). This was noted primarily in 4th-grade classes where teachers used engaging instruction that was relevant to learners' everyday lives.

Ramnarain and Fortus (2013) underscore the importance of instruction in their study on teachers' perception of the new content of the Revised National Curriculum Statement. They found out that those teachers who had sound subject matter knowledge had problems in delivering lessons that were meaningful and fostering comprehension on the new topics (Ramnarain & Fortus, 2013). Shulman (1986) poses the question: how can an expert teacher transform the subject content matter into what learners can comprehend meaningfully in the classroom? Pretorius, De Beer, and Lautenbach (2014) claim that there is a generation gap on how teachers were taught and how the learners of today should be taught; surprisingly teachers are seen teaching the way they were taught. Therefore, there is a need to professionally develop teachers to teach for conceptual understanding. Pretorius et al. (2014, p. 555) argue that "science teachers need continuing professional development to invigorate their teaching practices to enthuse learners, motivating them to achieve better results …."

Between 2011 and 2013 the DBE trained teachers and subject advisors in preparation for the successful implementation of the CAPS, which focussed mainly on new content (Physical Science, Mathematics & Business Studies) and assessment plan (Department of Education, 2014b). In February 2013, I was privileged to be one of the teachers to be trained as a facilitator together with subject advisors. The training of the subject advisors was initially scheduled for three days but was cut down to two days only. The training of teachers by subject advisors was reduced from five days to three days. In all cases, the days were compacted due to the lake of adequate financial funding for the entire training program. Such kind of training has been criticised in South African literature as a one-size-fits-all approach that has shown limited effectiveness (Ndlovu, 2011).

To raise the 2014 NCS results, the DBE engaged learners in vigorous revision programmes through Saturday schools, camps and revision materials, especially for mathematics and science. All the same, the results do not reflect the efforts and resources that were invested in the preparation of learners for these subjects. Kriek and Grayson (2009) criticised the approach of drilling learners in how they should answer questions in the examination. They further note that such endeavours do not help or improve the education system although it can help individual learners. It is, however, noteworthy that the long-term plan for the improvement of the results should involve the empowerment of the teacher with sound knowledge of pedagogy that enhances learner-meaning making in the classroom. The Project SMILES carried out by the University of Stellenbosch using identification questionnaires, teachers indicated that they need programmes that improve their skills in orchestrating cooperative learning approaches, enacting learner-centeredness pedagogy and adaptive solving approaches among other requests (Ndlovu, 2011).

Even though teachers face challenges such as limited resources and large classes, they are still expected to have high pass rates at Grade 12 external examinations. All stakeholders in the education system (parents, communities, universities, department of education, politicians, etc.) pressurise teachers to improve the examination results. To alleviate teachers' continued frustrations and yearly castigations over the results, researchers must strive to provide teachers with continuous intellectual resources for the planning and implementation of quality professional development. Such teacher professional development should influence teacher's classroom behaviours in a way that lead to enhancement in learner performance (Harwell, 2003). One-size-fit-all workshops are not adequately carved for engendering effective change in teacher professional development. Teacher professional development programs should be held over a long period and should be prioritised over individual workshops and seminars, which are usually one-time events.

Dan Hull writing the preface for the book Teacher professional development said that it's not an event, it's a process (Harwell, 2003). He further argues that improved student performance does not come as a result of more accountability, high stakes tests, more time on task, new curricula and materials etc. but enhanced teaching strategies directed on average students (Harwell, 2003). Although South Africa attained independence in 1994 and has experienced significant curricula changes, improved teaching material and assessments standards, there is little significant improvement in science learner performance.

1.3 Purpose of the study

The major focus is to evaluate what is happening in the South African Physical Science classroom. How is the teaching and learning process unfolding in real life classroom practices? To what extent do teachers of Physical Sciences from Grade 10 to 12 foster meaningful learning to enable learners conceptually understand and acquire scientific content knowledge? This study argues for a prototype approach to teaching that enhances meaningful learning in the science classroom. Using pedagogical link making, as developed by Scott and friends, the study compares the practices of individual cases focusing on how they support conceptual learning. The study seeks to provide insightful facts from the actual practice instead of relying on conferences and workshop feedbacks about what should be done to teach for conceptual understanding. Observation of teachers' practices would be of importance to understand, why learners cannot answer conceptual questions. One of the issues that are addressed in this thesis is: to what extent does the CAPS curriculum support conceptual understanding?

1.4 Research Questions

My study intends to address the following questions

1 To what extent do the Physical Science CAPS documents support the progression and coherence of Chemical Change concepts at FET level?

2 To what extent do FET teachers make connections between concepts in developing a scientific story in the teaching of electrolytic cells and its fundamental concepts at the senior secondary level?

3 To what extent do teachers engage in meaning-making strategies in the teaching of electrolytic cells and its fundamental concepts at the senior secondary level?

Given this backdrop, this study explores the width and breadth of teaching strategies that foster meaning-making in the science classroom.

1.5 Significance of the Study

The findings of my study are expected to reveal some of the factors that affect teaching for conceptual understanding in the teaching of the electrolytic cell and its fundamental concepts. Through the critical lens of pedagogical link-making, possible solutions could be found to address the challenges and to recommend remedial measures that can be followed by teachers for meaningful and effective teaching. This study aims to expose the current teaching practices and how they differ from PLM approaches that embody the traits of teaching for scientific conceptual understanding. The strengths and weakness of the present methods are measured against the PLM traits to inform curriculum developers, researchers, and curriculum implementers of what to do to accomplish meaningful learning in the science classroom.

The study is also expected to conscientious researchers with another teaching approach among many others, that could be used to improve the teaching practice of science. Although PLM is not a competing teaching strategy to the body of pedagogies recorded to date, in my view, it adds to the big puzzle of mediating meaning-making in science classrooms.

From this thesis, a book section has been published with the Royal Society of Chemistry (appendix F) and a paper is ready for submission to African Journal of Research in Mathematics, Science and Technology Education (AJRMSTE) (Appendix G). Some of the findings of this study have been peer-reviewed and presented as short papers at regional and international conferences, namely in the Southern African Development Community (SADC), and Europe, as indicated in the list of outputs given below.

Msimanga, A., & Mudadigwa, B. (2019). Supporting Argumentation in Chemistry Education in Low-income Contexts. In S. Erduran (Ed.), *Argumentation in Chemistry Education: Policy and Practice* (pp. 275-291). London: Royal Society of Chemistry.

Mudadigwa, B., & Msimanga, A.,(Date). Exploring teacher pedagogical practices that help learners make connections during the teaching of the Electrolytic cell at senior secondary. Future publication in AJRMSTE.

Mudadigwa, B., & Msimanga, A. (2018). How spiral is the CAPS curriculum on the topic Electrolytic cell and its fundamental concepts Proceedings of the XVIII Symposium of the International Organization for Science and Technology Education (IOSTE) hosted by Malmö University and Stockholm University on August 13-17, 2018 Malmö, Sweden (Short Paper)

Mudadigwa, B., & Msimanga, A. (2018). An exploration of teachers' pedagogical practices in helping learners make connections in the teaching of the Electrolytic cell at senior secondary. Proceedings of the 26th Annual meeting of the Southern African Association of Research in Mathematics and Science Technology Education Conference hosted by University of Botswana Gaborone, Botswana on the 16 January - 19 January 2018 (Short Paper).

Mudadigwa, B., & Msimanga, A. (2017). Challenges in teaching Physical Science for conceptual understanding a case of Gauteng East Schools: Teachers' Voices Proceedings of the 25th Annual meeting of the Southern African Association of Research in Mathematics and Science Technology Education Conference hosted by the Central University of Technology. Bloemfontein, RSA on the 17 January - 20 January 2017 (Short Paper).

Mudadigwa, B., & Msimanga, A. (2016). Exploring the use of link making for meaningful learning in the teaching of Chemical Change at Grade 10 to 12. Proceedings of the 24th Annual meeting of the Southern African Association of Research in Mathematics and Science Technology Education Conference hosted by the Tshwane University of Technology Arts Campus Pretoria RSA on the 12 January - 15 January 2016 (as part of a Symposium).

1.6 Limitations of the Study

The outcomes of this research may not be generalised because they are unique to particular individual teachers who participated in the study and unique to the context where the teachers were working. Since this is a multi-case study comprising a single, unique unit or naturally single members, it does not represent the whole population of teachers in the three educational district of Gauteng province. A case study is perceived to be an inadequate basis for generalisation (Stake, 1978). However, the information and evidence gathered for this study informs academics and teachers about the state of teaching scientific knowledge for conceptual understanding.

The study of this nature produces a large data set, which is prone to human error during the observation of the participating teachers, as well as in transcription, transformation and analysis. As my research was time bound, it could not allow me to be at a research site for long periods to fully substantiate the behaviour of teachers and learners. I am only making inferences about the teachers' practice from a limited number of observations of their teaching. This study does not seek learners' opinions on their learning of science. Thus, I make my conclusions with caution albeit with confidence that my analysis reveals aspects of a true story of science teaching in this context.

1.7 Ethical considerations

According to Mouton (2001), ethics is about the wrongs and rights of carrying out research that must conform to morally acceptable norms and values of scientific research. Ethical matters arise when researchers interact with living species and the environment. The researcher needs to seek permission from responsible bodies to conduct his/her research (Mouton, 2001).

As my research is focused on human beings, I was ethically responsible for the protection of teachers' and learners' rights who were the participants as well as schools they were in. I sought permission from the university (Appendix A) and the Gauteng Department of Education (GDE) (Appendix B), to carry out the research in Gauteng East, Ekurhuleni North and Johannesburg Central Districts in Gauteng province. Upon receiving the protocol number 2016ECE008D, I administered the consent forms and information sheet to the principals, the teachers, learners, and parents (Appendix C). The information sheets sought permission to interview teachers, video and audio tape both teachers and learners, for three lessons from Grades 10 to 12 in each school. Participants were assured of anonymity like no other person other than my supervisor, and I had access to the video and audio recordings. Participation was voluntary, and participants were free to withdraw at any time without being prejudiced in any way. Pseudo names of schools and teachers were used in the presentation and analysis of data and names of learners quoted in all excerpts of this study are fictitious.

1.8 Overview of Methodology

The study followed the explanatory interpretative qualitative research paradigm with a multicase study methodology. The research's five participating in-service teachers were drawn from five different schools in three different districts across Gauteng province. Eighteen lessons were audio and video recorded, six lessons from each grade in the FET phase. Each teacher was interviewed after his or her set of three lessons were observed. Grade 10 teachers were observed while teaching Reactions in aqueous solutions. Grade 11 teachers were teaching redox reactions, and Grade 12 were observed while teaching Electrolytic cells.

1.9 Conclusion

I began this chapter with some reflections on my educational background and my perception of what constituted good teaching and learning practice as drawn from my high school teachers. The next section discusses how policies and stipulations contained in the CAPS and the IQMS documents are aligned to the pedagogical link-making approach. The scene of the problem was set when the analysis of the TIMSS assessments results revealed how South African learners are struggling to meet international standards in Physical Science. Scrutinising 2014 NCS National examination results in comparison with prior years, unveiled that most learners are struggling with the subject Physical Science. Analysing how Chemistry Paper 2 has been tackled in previous examinations particularly the 2014 cohort, the pioneers of the current curriculum, zeroed on Chemical Change as the difficult topic in Chemistry. Arguments were made with reference from the literature that it is time we focus on how to foster meaning-making in the classroom. Through capacitating the teacher with appropriate teaching pedagogy, that pushes our agenda towards learner comprehension of the subject matter. Elucidation of methods has been made of how I intended to collect data to evaluate the use of pedagogical link-making. The pedagogical link-making approach has its roots in social constructivism. The next chapter presents a review of related studies on this teaching approach.

CHAPTER 2

Literature review and Theoretical background

2.0 Introduction

Different teaching and learning theories exist. Some of them are the behaviouristic, cognitivistic, positivistic, constructivist, collectivistic, and thematic holistic. Teachers are usually guided by teaching theories and methodologies that they have been exposed to or what they believe will bring forth the intended learning results in their classrooms.

Teachers who subscribe to behaviouristic, cognitivistic and positivistic theories tend to plan their teaching strategies in a teacher-centred approach. However, those who are guided by constructivism, collectivistic, and thematic holistic theories organise their teaching instruction in social context milieus (Jaramillo, 1996). Jaramillo (1996) argues that the teaching strategy and curricula that educators implement obliquely replicate the learning theories that they believe. The theoretical framework developed for this study is centred on social constructivism, and the analytical frame derived from the pedagogical link approaching will be discussed in detail from literature.

2.1 Constructivism

Recent research in science education explains pedagogical approaches that can equip learners from diverse backgrounds with the necessary skills to learn science. Consequently, Science Technology and Society (STS), Inquiry-Based, Active Learning and Constructivist approaches have been explored in previous studies.

These pedagogical approaches are meant to address the issue of learner involvement in the process of teaching and learning of science and to produce scientifically literate learners. In South Africa (SA), there have been several reviews of the curriculum since Curriculum 2005 (C2005), the National Curriculum Statement (NCS) and the Curriculum Assessment Policy Statement (CAPS). These curriculum changes consistently call for active learner involvement in the classroom.

Constructivism is learner centred. Learners create new knowledge and understanding based on previous experience (Jaramillo, 1996; Kiraly, 2000; Taber, 2008; Von Glasersfeld, 1991). Taber (2008) posits that substantial and meaningful expertise cannot be transferred directly from the teacher to the student. Instead, learning involves the reconstruction of experience that the teacher can scaffold.

There are different perspectives of constructivism some of which are the cognitive, social and situated constructivist approaches. These constructivist paradigms agree on the underlying feature of constructivism that learners' prior knowledge is a prerequisite for learning new concepts. Mortimer and Scott (2003) assert that constructivists share two main ideas about science teaching. Firstly, learning calls for the active intellectual participation of students. Secondly, the student's prior knowledge is essential for the acquisition of new concepts. These three constructivist approaches concur that learners are not blank slates, *tabula rasa*, neither are they empty vessel but they come into the classroom with prior knowledge acquired through previous experiences (Oleson & Hora, 2014; Piaget, 1964, 2003). I will now discuss cognitive and social constructivist approaches, separately.

2.1.1 Cognitive constructivism

Cognitive constructivism refers to how the individual learner can acquire, construct, and understand knowledge (Von Glasersfeld, 1991). Cognitive constructivism, as propounded by Piaget, a French-Swiss developmental psychologist describes how children develop cognitive structures. Piaget (1964, 2003) argues that knowledge is not a pattern of certainty. He asserts that to know an object one has to act on it, modify and convert it and understand the creation of the object (Piaget, 1964, 2003).

Bonk and King (2012) state that cognitive constructivism makes learning a personally relevant and meaningful effort that relate learning to hands-on ideas and personal experiences. Piaget further says that knowledge is spontaneous in its development and that the knowledge constructions are a consequence of developmental processes. The development of mental structures leads to learning, and learning is provoked by stimuli from the environment (Piaget, 1964, 2003).

The underlying principle of cognitive constructivism is that learners construct their knowledge through experience and active participation in the handling of objects within the environment (Powell & Kalina, 2009). The emphasis is on the active engagement of the learner in making sense and meaning of his surroundings. The learner acquires knowledge through experience, assimilation, accommodation and equilibration (Piaget, 1964, 2003). *Assimilation* can be described as harmonising a new experience into an existing cognitive structure (schema), whereas *accommodation* is the ability of a learner to alter an already existing schema because of knowledge gained through a new experience and *equilibration* means a quest for cognitive solidity through assimilation and accommodation ((Piaget, 1964, 2003; Powell & Kalina, 2009).

The learner acquires knowledge through an authentic activity and dealing with the activity as a whole and not in parts. The activities must be challenging, real, exciting and meaningful to the learner (Von Glasersfeld, 1991). The learner must be allowed to make mistakes and correct them as they solve the problem independent of the teacher, who should act as the facilitator of the whole learning activity. Piaget (1964, 2003) argues that learners should be given tasks that are correspondent to their intellectual developmental stage lest learning is hindered, as the new knowledge will not be accommodated in the existing schema. Other classic psychologists support this ideology that development always precedes learning and that if a child's intellectual structures have not developed to the extent that he/she is adept of learning a specific concept, then no teaching will attest worthwhile (Von Glasersfeld, 1991). Piaget recognises the significance of social involvement as he posits that in linguistic communication children can learn language from adults but can only understand it if the child is in a right state of understanding the information (Piaget, 1964, 2003).

Further development in constructivist thinking was the Vygotskian social constructivism incorporates in the basic tenets of constructivism, the role of social interaction.

2.1.2 Theoretical Framework: Social Constructivism

Lev Vygotsky is one of the leading psychologists to advocate social constructivism. He explained the difference between human beings and animals by noting that social experiences model human behaviour (Vygotsky, 1978). Vygotsky argues that the process of internalisation is an outcome of socialisation by the community members for the development of higher mental functions of the learner (Vygotsky, 1978). He suggests that language is the primary tool in the development of higher mental functions. Vygotsky believed that learning and development are interrelated (Vygotsky, 1978). The two facets of social constructivism, internalisation and language are discussed below.

2.1.3 The process of internalisation

Vygotsky and other social constructivists believed that human mental development was a product of the individual's social interaction and social experience (Vygotsky, 1978). Psychological tools are the vehicle that can translate social interaction into psychological principles and these tools differ from culture to culture through human history. Vygotsky (1978) noted that psychological tools change the processes of thinking by directing the mind what to do.

The development of higher mental functions first takes place on an interpersonal plane (interpsychological plane) through socialisation and later on the intrapersonal plane (intrapsychological plane) (Vygotsky, 1978). The learner's cognitive structures develop because of direct interaction with society. Bonk and King (2012, p. 29) argue that "learning is influenced by social interactions, interpersonal relations, and communication with others". A learner is a participatory subject who attains knowledge through direct involvement with more knowledgeable members of the society. Socialisation is the vehicle that drives the development of higher mental functions leading to internalisation (Zimmerman, 2013). Internalisation is defined as an inner rebuilding of an exterior process (Vygotsky, 1978). Internalisation happens in three stages (Vygotsky, 1978, pp. 56-57).

> *An operation that initially represents an external activity is reconstructed and begins to occur internally.*
>
> *An interpersonal process is transformed into intrapersonal one.*
>
> *The transformation of an interpersonal process into an intrapersonal one is the result of a long series of developmental events.*

The internalisation process is socially rooted (Gee, 2012); the learners can only be able to conceptualise concepts as a result of interaction with others in the classroom. The others can be knowledgeable peers or the teacher. Transformation of ideas is not an event, but a process which is achieved over a period. Scott et al. (2011) argue that teaching and learning of Science concepts must be covered over an extended period. That is, the sustenance of knowledge construction in the learner's mind (internalisation) involves continuity of progressive concepts over a period on social milieu (Powell & Kalina, 2009).

2.1.4 Language as a Tool

Science has a specific language that is different from everyday language. For conceptual understanding, learners need to be conversant with the scientific language. Mortimer and Scott (2003) argue that the introduction of scientific language constitutes science learning. Learners should be socialised in the scientific language of chemistry. Oyoo (2009) argues that the appropriate use of the scientific language by learners is important. Therefore, teaching the proper scientific language to learners is a tool that develops their conceptual understanding of the subject in this particular case the language of chemistry.

Vygotsky (1978) argues that it is fruitless and impossible to teach concepts in its direct form. He further contends that explaining concepts directly, does not achieve much but "….usually accomplishes nothing but verbalism, a parrot-like repetition of words by the child, simulating a knowledge of the corresponding concepts but covering up a vacuum" (Vygotsky, 1962, p. 83). Meaningful learning advocates teaching concepts in connection with the previous knowledge linked to other relevant concepts within the subject. This is what Scott et al. (2011) refer to as continuity or what the Department of Education (2011) term coherence. Conceptual continuity or coherence ensures the progression of concept development, which brings about conceptual understanding as learners make meaning of connected concepts.

The teacher's role is to make the scientific language available to learners in the classroom. The teacher must be able to distinguish between the use of words in the everyday language and in science language. When the distinction between the scientific and everyday use of language is made unambiguous (Mortimer & Scott, 2003), the emergence of alternative concepts is reduced. Failure to link scientific words to everyday use and differentiate their meaning in the classroom leaves the learner with arbitrary concepts (Ausubel, 1977). If such concepts remain disconnected, they interfere with the building of ideas and disrupt the successful construction of meaning-making. Concepts must be clearly linked to show progression. The current CAPS curriculum advocates this coherent development of concepts in a spiral manner.

2.3 Spiral Curriculum

Coelho and Moles (2016) describe the curriculum as all the experiences planned and exposed to the learner to accomplish the learning goals. There are four components of the curriculum, namely, the subject content, pedagogical content, assessment and evaluation processes. However, this study focuses on the subject matter aspect of the curriculum deemed the content curriculum. Pellegrino (2006) argues that content curriculum consists of knowledge and skills that teachers teach, and learners learn, it includes a scope of subject matter sequenced for learning. The nature and extent of the subject matter is the thrust of the spiral curriculum. The CAPS Physical Science curriculum is structured spirally. One of my research questions, is: to what extent do the Physical Science CAPS documents support the progression and coherence of Chemical Change concepts at FET level?

Jerome Bruner coined the term spiral curriculum. Bruner emphasises the structure of the curriculum for the meaningful learning process to take place. Bruner (1960, p. 7) argues that "Grasping the structure of a subject is understanding it in a way that permits many other things to be related to it meaningfully. To learn the structure, in short, is to learn how things are related". According to Bruner (1960), at the bottom of the structure are fundamental concepts on which new connected complex concepts are to be built on. Following Bruner's argument, Harden (1999) defines a spiral curriculum as one in which there is a frequentative or repetitive revisiting of concepts, or themes throughout the curriculum. Grove, Hershberger, and Bretz (2008) describe a spiral curriculum as an approach where essential knowledge of a subject is covered at different stages of comprehension. Gibbs (2014, p. 40) argues that spiral curriculum is where "students revisit a topic, theme, or subject several times throughout their schooling, where the complexity of the topic is increased with each visit to the new learning is connected to the old learning". Some spiral curriculum facets emerge from these definitions, these are essential concepts should be the basis of a structured curriculum, learners' previous knowledge is critical, concepts learned should be interconnected, ideas should be hierarchical, should be revisited in-depth and in increased complexity. The focus of this research is on analysing how spiral and progressive is the topic electrolytic cell from Grade 10 to 12 in the South African CAPS curriculum.

Bruner (1960) presented four claims that can be taken into consideration when teaching the essential concepts of a subject. The first is that the subject is made more comprehensible by understanding its underlying concepts. The second pertains to the fact that human memory easily forgets the undetailed structured pattern. That is, the human mind does not internalise a disconnected set of concepts. Bruner (1960) asserts that the knowledge learned without an adequate structure to tie it together is quickly forgotten. Thirdly, the primary strategy of teaching for meaningful learning is anchored on understanding the essential principles and concepts of the structure rather than the mastery of disconnected facts. Fourthly, revisiting learnt ideas in higher grades bridges the gap between fundamental concepts and high order and advanced concepts. Bruner's fourth claim calls for the smooth transition of content through coherence from primary to secondary, and to tertiary levels. As mentioned earlier, this study is limited to analysing the spirality of content of electrolytic cells and its fundamental concepts within the FET Grades 10 to 12. The starting point of the spiral curriculum is where essential concepts are covered and mastered at a lower level and revisited in-depth later on for conceptual understanding.

Bruner's fourth claim resonates well with the notion of coherence and hierarchical structure as propounded by Novak (2002) as well as the idea of promoting continuity developed by Scott et al. (2011), together with the concept of progression and coherence propounded by the Department of Basic Education of South Africa. The central theme for all is a broad base of fundamental concepts at the starting of science education with some interrelated concepts that then get linked to more difficult and well-connected higher order concepts. Later, Bruner (1960) acknowledges that such a process enhances the mastery of the interrelationship and structure of the knowledge. Bruner (1960) further argues that once the concepts are mastered at lower levels, they are revisited and reconstructed at a higher level to a new level of intellection and extensiveness. For a better understanding of the nature and implementation of the spiral curriculum, let us look at Harden's four features of the spiral curriculum.

According to Harden (1999), the first feature is that learners are made to revisit topics, concepts or themes, on some occasion. In the SA context, this would be a phase or grade. When dealing with the topic of electrolytic cells, for instance, the essential notion of Reactions in aqueous solutions is covered in Grade 10. The topic includes concepts such as redox reactions, dissolutions of salts, acids and bases and precipitation reactions (Department of Education, 2011). Harden's second feature pertains to increasing successive levels of difficulty and each revisit has new additional objectives with the presentation of renewed learning prospects to accomplish the ultimate inclusive objectives. In the example of redox reactions, learners are only introduced to essential reactions, at Grade 10, and then in Grade 11, the renewed aim is for them to be able to distinguish between the oxidised and the reduced species. Then in Grade 12, they cover the application of redox reactions and calculation of redox potentials. According to Harden (1999, p. 141), each revisit must "bring new knowledge or skills relating to the theme or topic; more advanced applications of areas previously covered, and increased proficiency or expertise through further practical experience". Harden's third feature as derived from Bruner's learners' previous knowledge.

New skills and knowledge introduced in a grade are connected and linked directly back to prior learning in preceding phases of the spiral. That is, in learning redox reactions in Grade 11 learners should be able to connect to concepts of Reactions in aqueous solutions at Grade 10. Constructing concepts progressively with time helps learners to integrate new ideas with prior knowledge (Fortus, Sutherland Adams, Krajcik, & Reiser, 2015). The fourth feature relates to the development of learner increasing competence with each visit of each spiral stage. Harden (1999) asserts that learner competence increases at each stage of the spiral until the final overall objectives are achieved at the exit grade of the phase. However, the competence of the learner can be assessed at each stage. Thus, for chemical reactions the highest competence is expected at Grade 12 when they cover Electrolytic cells and Galvanic cells (not the focus of this study), linking back to Redox reactions (Grade 11) and Reactions in aqueous solutions (Grade 10). The different stages of the spiral curriculum can be represented as shown in the diagram below.

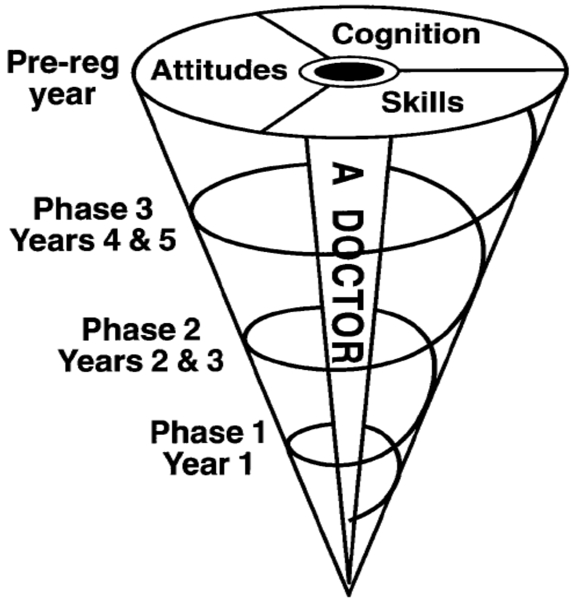


Figure 2.1: four spirals in the curriculum (Harden, 1999, p. 142)

Figure 2.1 above depicts the four phases of the medical curriculum at the University of Dundee (Harden, 1999). In the high school set up, it is not the doctor moving up the spiral stages, but the learner. The CAPS Physical Science curriculum has three steps instead of four because of the three grades in the Further Educational Training Phase. Each concept covered in Grade 10 should be revisited in Grade 11 and 12 with increasing complexity, depth and difficulty. The spiral curriculum has been put to the test in several countries around the globe.

Research has been conducted on the implementation of the spiral curriculum. For example, Grove et al. (2008) found that the spiral approach introduced at Miami University decreased student attrition in an organic chemistry course. Before the introduction of the spiral curriculum, student attrition was between 30-50%, and it was reduced to 13.1%. Apparently, the approach helped students to understand the organic chemistry concepts conceptually. In another study, Coelho and Moles (2016) investigated the effect of spiral curriculum on medical students and found that students perceive a well-structured cohesive spiral curriculum to be beneficial to learning. However, the impact of a spiral curriculum was only felt in the final stage of the programme where there is a consolidation of all learning objectives of the other preceding stages. In the South African context, Sibanda and Hobden (2016) did a study on the sequencing of essential chemistry topics by physical science teachers.

They found a mismatch between the curriculum sequence and the way teachers preferred a series of topics during their teaching. Sibanda and Hobden (2016) further assert that the past examination papers and the current CAPS Physical Science curricula exhibit little reasoning sequencing of chemistry topics besides the necessity of having a spiral curriculum.

Nonetheless, the Department of Basic Education claims that the curriculum is spiral, and it helps learners to acquire scientific knowledge meaningfully because its content is coherent, hierarchical and progressive. Hence, the science policy document indicates that the “content and context of each grade shows progress from simple to complex” (Department of Education, 2011, p. 5). This thesis focuses on the extent the Physical Science curriculum is progressional or spiral. Furthermore, the research examines the extent to which teachers illustrate and explain the interrelatedness of chemistry concepts in Electrolytic cells and its fundamental concepts under Chemical Change in their teaching.

2.5 Meaningful Learning and Coherent learning Material

According to Ausubel (1977), meaningful learning is the ability of a learner to relate non-arbitrary and non-verbatim new knowledge to pre-existing knowledge. The learning material should trigger conceivable links connecting new and pre-existing knowledge (non-arbitrary) in the learners’ cognitive structures. That is, learners should be able to make connections between scientific explanations and real-world phenomena, every day and scientific ways of explaining and scientific concepts. The meaningful learning material should not be presented to learners in words only. Preferably, the use of modes of representations, analogues, and moving between different scales and levels of explanation should be employed to reduce the verbalisation of the content (Ausubel, 2012).

Novak (2002) suggests that meaningful learning is the construction of valid meanings. It is also the reconstruction of misconceptions (invalid meanings) in the learners' cognitive structure. Ausubel (2012) acknowledges that knowledge building or construction has a bearing on learning for conceptual understanding.

The term conceptual understanding itself refers to the internalisation of the interlinking concepts in the mental structure of the learner (Ausubel, 2012). Konicek-Moran and Keeley (2015) describe conceptual understanding as the learners' ability to think of a concept, apply the concepts in different scenarios, explain it in their own words and construct a mental or model of the idea learned. However, the organisational structure of thoughts has a considerable impact on the internalisation or conceptualisation of ideas by learners. The DBE recognises this and claims to have structured the concepts in CAPS progressively and coherently.

The quality of meaningful learning in the teaching and learning process is depended upon the organisational quality of the learning material and its conceptual richness (Novak, 2010). The organisational quality of the learning content is what Scott et al. (2011) refer to as pedagogical link-making to promote continuity. The DBE uses the word coherence of the subject matter. Therefore, the learning material should be organised in such a manner that it is coherent. However, the subject matter may be well organised, but it is the responsibility of the teacher to help learners to construct.

Chemistry is perceived as a difficult subject (Sirhan, 2007). Chemistry is made more difficult by the poor organisational content structure. Sirhan (2007) further argues that the arduousness of the subject is compounded by the way the concepts are organised for teaching and learning. Similarly, Selvaratnam (1993, p. 824) argues that Chemistry has been made unnecessarily complicated because of how concepts are unorganised. Such unorganised ideas cause teachers and learners to resort to memorisation and rote learning (Novak, 2010).

One cannot dispute the power of rote learning or memorisation in helping learners pass examinations. Learners can achieve the required performance to pass examinations through such memorisation. When meaningful learning does not happen, learners are deprived of conceptual understanding. Prosser and Trigwell (1999, p. 59) define rote learning as “a mechanical act without thought of the meaning”. Selvaratnam (1993) criticises the emphasis on memorising laws and definitions of terms in the teaching of science. He argues that memorisation is time wasting and hinders recall of essential knowledge from memory, consequently affecting conceptual understanding. When learners are made to accumulate long lists of disconnected concepts compiles the learner to learn through rote memorisation (Park, Anderson, & Yoon, 2017).

Deep memorisation is identified as a method that is used by learners in studying for examinations (Prosser & Trigwell, 1999). Meaningful memorisation is differentiated from rote learning (meaningless memorisation). In the former, learners repeat the text to be learned several times focusing on a different aspect with each repetition (Prosser & Trigwell, 1999). This is done in a manner that deepens understanding. Novak (2002) also noted that learners achieve quite well in examinations through memorisation of facts. He, however, suggests that the knowledge acquired through memorisation is soon forgotten as it is irretrievable from long-term memory. He further argues that even if it is retrieved learners hardly apply it to solve problems in new contexts. The DBE is lamenting the poor performance of Grade 12 learners in the topic on Chemical Change in general and particularly the Electrolytic cell. The department found that learners struggle with questions that demand conceptual understanding (Department of Education, 2014b).

Chittleborough, Treagust, and Mocerino (2002) researched constraints to the development of first-year university learners’ mental models of chemical phenomena. They found that even university learners used memorisation. Those learners who had Chemistry as a subject from high school had distorted and disjointed mental models as demonstrated by their recounting of memorised definitions. They also interviewed learners who confessed that most concepts were rote learned and that they could not remember much of it even if they had passed the examinations (Chittleborough et al., 2002). This observation suggests that rote learning encourages memorisation of concepts without a deep understanding that learners are not able to integrate existing knowledge with the new experience. Sirhan (2007,

p. 3) argues that “While much can be acquired by rote learning (this often being reflected by the efficient recall in examination questions), real understanding demands the bringing together of conceptual understandings in a meaningful way.” The implication for teaching is that teachers must teach for conceptual understanding through meaningful engagement with learners. PLM is one of the ways that allow teachers to achieve this goal.

Meaningful learning is achievable when concepts are structured and organised systematically and coherently. The National Research Council (2012) argues that for learners to build deep, interrelated understandings of scientific phenomena and coherent science concepts, the curriculum must be cautiously arranged so that learners see and make the connections. A recent study of Grade 6 and Grade 7 science learners (Shin, Choi, Stevens, & Krajcik, 2017) found that learners who were exposed to coherent curriculum did perform better than those who followed a curriculum with illogical sequenced topics. A coherent curriculum is characterised by clear links between its core concepts across grades. Learners who are exposed to such a curriculum, experience continuous growth in conceptual understanding (Krajcik, Codere, Dahsah, Bayer, & Mun, 2014). My study sought to find out how learners were made aware of links between concepts in electrolytic cells. The focus of my investigation was to establish whether teachers taught chemistry concepts for conceptual understanding and not memorisation.

The teachers must be acquainted with the logical structure of the subject. Sirhan (2007) argues that it is not the duty of the learners to organise learning content in a coherent structure but that of experts (teachers and curriculum developers). Vygotsky (1978) states that learners should not only be shown the links but must also be involved in the identification processes of the links on a social plane (classroom discussions) for the internalisation that leads to a conceptual understanding of scientific concepts. The Department of Education (2006) indicates that when these links are shown to learners, they will appreciate the powerfulness of Physical Science in understanding the world. Hence, science should not be taught as disconnected lists of concepts. Instead, concepts should be constructed consecutively from ideas of previous grades which become learners' prior knowledge, and this is what PLM advocates for.

Fortus et al. (2015) stress that ideas that are built incrementally, over time, enable learners to develop their understanding of new ideas over their prior knowledge. They further argue that a well-sequenced curriculum that describes cliques of concepts that build upon one another to encounter anticipated learning goals can support the acquisition of conceptual understanding over time. Concepts develop as new ideas are linked together with old ones. However, learners do not always make such links on their own (Sirhan, 2007). They need to be helped to make such connections by the more knowledge other (teachers and peers). This happens best in meaningful social interaction, not through rote learning. The arrangement of concepts or topics in a coherent manner should facilitate new learning and provide a context for linking prior knowledge with new concepts (Selvaratnam, 1993). Hence, my study sought to find out whether there is an adequate emphasis on teaching for conceptual understanding through adequately organised learning content from Grade 10 to 12.

2.6 Concept Mapping

In this inquiry, the focus is not on learner's concepts mapping but on how the scientific concepts are intertwined as the teacher engages learners in the teaching and learning process. I developed concept maps as an interpretation of the teachers' layout of the lesson presentation. Therefore, concepts maps are not only of benefit to learners but also assist teachers in teaching effectively without using rote-learning strategies (Novak, 1990). Davies (2011) acknowledges that concept mapping is an old tool which has a significant contribution to the teaching and learning progression for both teachers and learners and continues to direct education in the future.

Jacobs-Lawson and Hershey (2002) describe concept maps as a graphic and hierarchically organised representation of knowledge that enhances an individual's concepts comprehension. Concept maps consist of interrelated concepts connected with linking words that indicate the relationships between any two ideas. A good concept map should be hierarchically organised, that is, general concepts at the top and specific concepts cascading down to the bottom of the map (Novak & Cañas, 2008). The constructions of concept maps emanate from a focus question, which provides a context of events that seek to enhance the conceptual understanding of a phenomenon. Hierarchical order and cross-links characterise good concepts maps. Cross-links and lines depict relationships between concepts in different knowledge domains of the concept map (Novak, 2010). The ability of the learner to draw a hierarchically organised concept map with cross-links signifies creative thinking and exhibits a conceptual understanding of the subject matter.

Concept mapping is a useful means to characterise changes in the cognitive structure of learners, and it assists them in learning meaningfully (Jacobs-Lawson & Hershey, 2002). They also help in the organisation of content and encourage learners to be in charge of meaning-making in their learning. Özmen, DemİrcİoĞlu, and Coll (2009) argue that when learners are with concept mapping coupled with practical activity, reduces learners' misconceptions, enable their concepts linking and is more enjoyable. Cavlazoglu, Akgun, and Stuessy (2013) also point out that when concept maps are used as a scaffolding tool, they necessitate the mediation of learner misconceptions and eventually reduce the emergence of misconceptions.

Novak (2010) suggests that concept mapping is a robust method that facilitates meaningful learning and can be used as an assessment tool to assess a learner's conceptual understanding of the subject matter. Concept maps can be used to assess an individual's or a group's conceptual understanding of the content taught (Jacobs-Lawson & Hershey, 2002). Concept mapping when used as an assessment tool, it helps teachers to monitor their learners' comprehension of the concept illustrated in the classroom (Cavlazoglu et al., 2013). The assessment can be done by asking learners to construct concept maps individually or in a group, at the beginning and the end of the lesson. Cavlazoglu and others found that when learners construct concept maps in small collaborative groups, facilitates and enhances the meaningful teaching and learning process. Hence, in a multi-dimensional subject like science, teachers must encourage group learner discussions in building concepts maps.

Novak (2010) rates concept mapping as a powerful technique that meaningfully facilitates learning and has the potential of scaffolding desired conceptual understanding. However, concept maps have been widely used for learner assessment (Burrows & Mooring, 2015; Cañas, Novak, & Reiska, 2015; Davies, 2011) but not for the teacher's lesson conceptual coherence assessment. Cavlazoglu et al. (2013) researched the quality of teachers' concept maps in workshops, and Starr & Krajcik (1990) worked with teachers in a professional development project. Both researchers assessed how teachers created concepts maps that exhibited coherence in the way they structured their concepts. However, none of the researches ventured into how the teachers interconnect scientific concepts during the teaching process. Against this background, the thrust of this study is to find out the nature of the organisational arrangement of concepts that can be depicted from the teacher's lesson presentation. The purpose is to determine if the way teachers arrange concepts during the teaching and learning process in a manner that enhances conceptual understanding.

Pedagogical link-making is adopted as an analytical, to investigate whether teachers use or do not use strategies that enhance conceptual understanding, (Scott et al., 2011).

2.7 Analytical Framework

Scott et al. (2011) developed an approach that is central to the process of teaching and learning of scientific conceptual understanding which they coined pedagogical link-making. The approach has its roots in social constructivism and focuses on how teachers and learners make connections between ideas in the on-going meaning-making interactions of classroom teaching and learning (Scott et al., 2011).

For the accomplishment of link-making, learners must be able to learn using links provided by the teacher during lesson delivery. The approach acknowledges that learners are not blank slates (Von Glasersfeld, 1991; Piaget, 1964, 2003) but bring with them naïve concepts that have to be linked to new knowledge for comprehension of Science concepts (Mortimer & Scott, 2003). The depth of understanding and comprehension of the new concept depends on the extent of links made by the teacher in the classroom. There are three forms of pedagogical link-making as identified by Scott et al. (2011) that play a significant role in meaningful learning will be discussed

here.

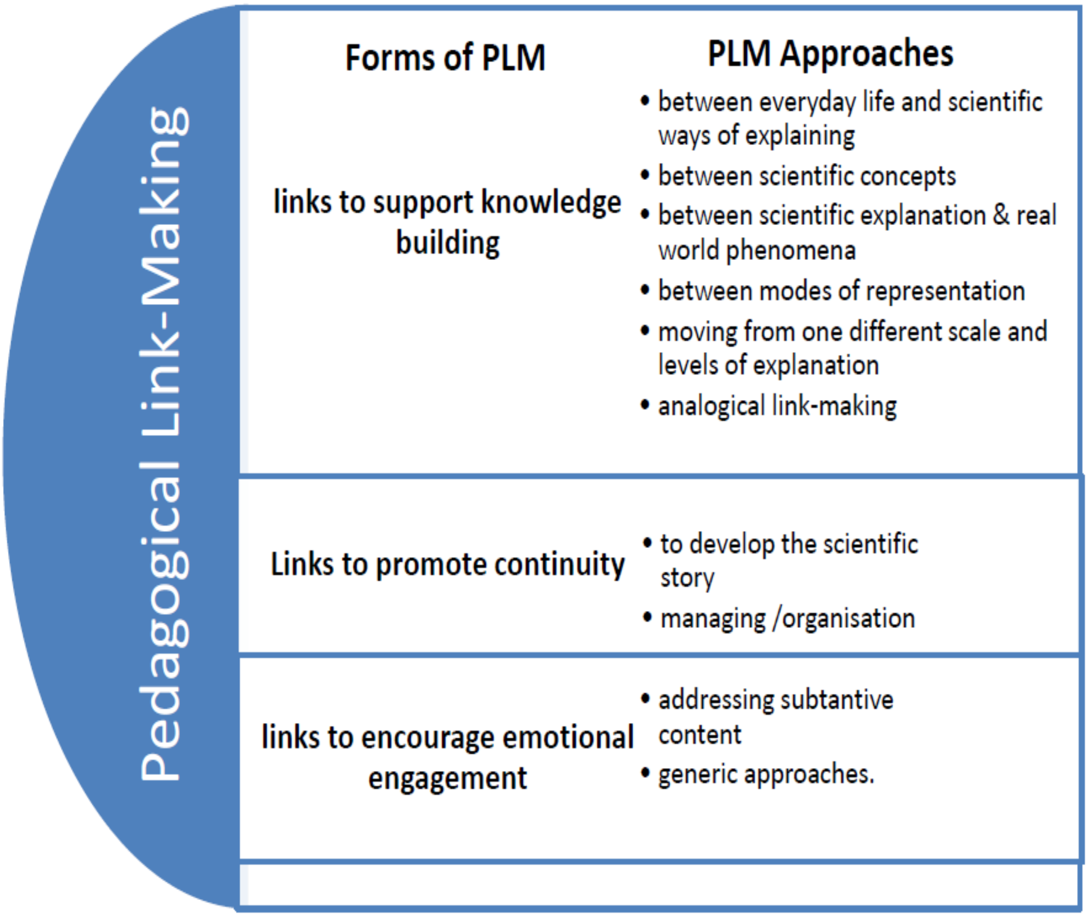


Figure 2.2: My diagrammatic conception of the forms of PLM and their approaches

2.7.1 Pedagogical link-making to support knowledge building

Pedagogical link-making to support knowledge building is described as "making connections between different kinds of knowledge to support learners in developing an understanding of subject matter" (Scott et al., 2011. p. 5). For conceptual understanding to take place, knowledge building must address how the scientific content must be taught. This section of pedagogical link-making involves six approaches that teachers must introduce in the classroom's interpsychological plane that support the creation of meaningful learning by the learners on the intrapsychological plane.

Approach 1: Making links between every day and scientific ways of explaining

This approach differentiates the way scientific concepts are described in everyday situations and the way the scientific community understand and explains them. Scott *et al.* (2011) describe the scientific idea as part of the scientific community's disciplinary knowledge produced by particular communities of scientists. These scientific concepts are not to be discovered by learners but can only be taught to them by more knowledgeable people with scientific language. However, the concepts are taught against a background of everyday explanations that are different from the scientific explanation, which Scott *et al.* refer to as natural means of speaking.

These two different explanations can have similarities in how concepts are explained at some point and can possess different explanations of the same concepts in some other instances. The similarities in explanations denote an overlap, and the teacher's objective is making links to integrate the two ways of explanations for conceptual understanding. Where the explanations are different, learning should involve making connections to differentiate the everyday way of explanation to the scientific way of explanation (Scott *et al.,* 2011).

An example of differentiating between the everyday way of explanation and the scientific way of explanation is the dissolution of salt under reactions in aqueous solution or solution chemistry. According to Uzuntiryaki and Geban (2005), the everyday way of explaining salt dissolution is that salt changes from solid form to a liquid form, or after dissolving, a new substance is formed, or, the solvent absorbs the salt. The scientific way of explaining salt dissolution involves describing salt as an ionic compound or a solute composed of positive (cations) and negative (anions) ions (Naah & Sanger, 2013).

$$NaCl_{(s)} \rightarrow Na^{+}_{(aq)} + Cl^{-}_{(aq)}$$

The process of salt dissolution involves three main steps particularly in water: (i) bond breaking of ionic bonds of the salt; (ii) breaking of intermolecular forces of hydrogen bonds in the water, and (iii) formation of bonds between water molecules and ions (hydration). Eventually, the salt is broken down into microscopic particles that are surrounded by particles of the water molecules through the process called dissociation.

Approach 2: Making links between scientific concepts

Besides linking of everyday and scientific ways of explaining by the teacher and the learners, meaningful learning of scientific knowledge also involves understanding how the scientific concepts themselves are interlinked. Meaningful learning of scientific knowledge requires that learners make sense of numerous interconnected science concepts and develop coherent knowledge constructs (Burrows & Mooring, 2015). In this approach, Scott *et al.* (2011) suggest that scientific concepts are not useful when treated individually. Instead, they are more valuable for conceptual understanding when they are connected, and their links are shown to learners. The primary focus is on the interrelated of scientific concepts within the topic and across learning areas. The teacher must be able to show or make learners conceptualise how concepts link within the topic and in the broader body of Chemistry. Scott *et al.* (2011, pg. 8) argue that "learning scientific conceptual understanding involves coming to recognise how the scientific concepts themselves fit together in an interlinking system." Therefore, this research is about how teachers present their teaching to foster conceptual understanding through knowledge building approaches.

Literature reports research how learners are supposed to interlink related scientific concepts and how they should be able to draw concept maps to exhibit their conceptual understanding (Cañas, Reiska, & Möllits, 2017; Cavlazoglu et al., 2013; Özmen et al., 2009). However, this study focuses on the teacher and not the learner, and the extent to which the teacher shows a conceptual understanding of the interrelatedness of the scientific concepts as he or she delivers his lessons to learners. The questions that are addressed in this study are: How conscious are teachers to a network of concepts about other topics? To what extent do the teachers emphasise the importance of such relations to their learners in the teaching of science particularly the electrolytic cells and their fundamental concepts at the secondary level? The analysis of making links between scientific concepts seek to answer these questions to address the research question; to what extent do teachers use knowledge building strategies in the teaching of electrolytic cells and its fundamental concepts at the senior secondary level?

To assess how teachers structure the concepts in their lesson concept mapping was used as the analytical tool. The knowledge to be acquired should be ordered in such a manner that it fits together in an interweaving scheme (Scott et al., 2011). The network of concepts should be structured hierarchically with the most general ideas at the top of the map and less general concepts at the bottom (Novak & Cañas, 2008). Scott et al. (2011) argue that a deep conceptual understanding will only be achieved when learners appreciate the relationships between related scientific concepts. For the learners to come to the desired level of learning, the teacher should be able to enact in his or her teaching the same principle of concept mapping that depicts hierarchically spiral concepts from general to specific.

Consequently, this study is not about assessing learners' conceptual mapping but trying to understand how teachers arrange the concepts they teach during lesson presentations. My argument is that the teacher should present well organised scientific concepts to enable learners to acquire orderly knowledge structures in their schema as maintained by Burrows and Mooring (2015). Hence, my focus is on how the teacher uses interlinking of concepts as a form of knowledge construction to achieve meaningful learning that leads to learners' conceptual understanding.

In the example of dissociation of salt given above the teacher must be able to link-make the concepts of bond breaking and bond formation during the dissolution of salt in water. When teaching Redox Reactions, learners must be shown how the concept of oxidation numbers and electron transfer are related during the simultaneous processes of oxidation and reduction (Jensen, 2009). Teachers who are teaching electrolytic cells at Grade 12 level, should be able to show the interrelatedness of movement of ions during decomposition of the electrolyte with concepts such as potential difference across electrodes and half-reactions. These topics on their own are considered difficult.

It was noted that concepts related to electrochemistry and electron transfer such as an oxidation-reduction process which are critical concepts learned in chemistry are associated with severe learning difficulties and with misconceptions (Basheer, Hugerat, Kortam, & Hofstein, 2017). In a survey done by Finley, Stewart, & Yarroch (1982) redox reactions were rated as one of the three difficult chemistry topics among chemical equilibrium and the mole.

To compact the difficult of redox reactions, galvanic and electrolytic cells, after their study with chemistry secondary school learners Akram, Surif, and Ali (2014) discouraged rote learning when teaching these topics. However, they encouraged the use of cooperative learning instruction and the use of designed teaching sequence for active learning.

Approach 3: Making links between scientific explanations and real-world phenomena

Making links between scientific explanations and real-world phenomena focusses on ensuring that science is not taught by a verbal process without concretising the concepts (Scott et al., 2011). This pedagogical tool deals with learner interest and relevance towards the scientific body of knowledge. To be able to define interest, and relevance as well as contextualise it according to Scott et al. (2011), I briefly explain the term motivation. Motivation is an internal state that boosts, stimulates, leads and sustains human performance (Rannikmae, Teppo, & Holbrook, 2010). Rannikmae et al. (2010) further argue that motivation is affected by learners' personal interest, fulfilment and activity enjoyment. Hence, this study sought to determine how teachers consider classroom activities that enhance or arouse learner interest during the teaching and learning process. Motivation can be categorised in two forms namely, intrinsic motivation (internal to the person), and extrinsic motivation (outside of the person) (Rannikmae et al., 2010). In this study, I will focus on extrinsic motivation.

Dierks, Höffler, Blankenburg, Peters, and Parchmann (2016, p. 3) categorise interest as "situational interest (emerging from the environment as a momentary psychological state), and individual interest (as an enduring and often stable disposition)". The latter is not investigated in this study, and I will only be interested in situational interest, which is emphasised by Scott et al. (2011) from which a draw my analytical tool. The argument in situated interest is that learning must precede an activity, which means learning comes after going through an action on the phenomenon to be learnt.

Prins, Bulte, and Pilot (2016) argue that when learners take part in an activity, they acquire knowledge which in turn affect learner action and consequently transform learner knowledge. Prins et al. (2016) further note that the emerging transformation process is a result of link-making between scientific concepts and an activity. That transformation of knowledge or understanding which take place in the learner's mind during or after an activity is the essence of meaningful learning which is the pivot of this study. Vygotsky (1978) points out that the weakness of Science lies in its richness in verbalism and lacks concreteness that enhances meaning-making in the learners. Therefore, my study sought to find how teachers could arouse learner interest through the use of activities such as practical work to reduce verbalising teaching of science.

When learning for scientific conceptual understanding, the learners should make links between the scientific phenomena to the real world (Scott et al., 2011). This pedagogical tool emphasises the relevance of the scientific concepts to the real world that the teacher has to carefully, deliberately and systematically select for learners' conceptual comprehension. The teacher must be able to saturate Science ideas with the concrete that arouses learner interest. The central role of a teacher is to lead learners through activities by instructing, encouraging, and ultimately letting learners do it on themselves (Prins et al., 2016). For example, electrolysis concept will be more relevant to learners if car batteries are used as an example of real-life phenomena where the idea is applied. Teaching the concept of electrolytic cells without the experimental activities of electrolysis, verbalises the idea and complicates the subject matter, to the detriment of conceptual understanding.

In this approach, Scott et al. (2011) encourage teachers to know the learning demands of each concept. Teachers must know how to organise the learning material by appropriately sequencing ideas, that is, teaching direct and straightforward phenomena and move on to more abstract concepts later. For example, in the teaching of Redox reactions, oxidation numbers is a prerequisite concept to be taught before balancing or learning about net ionic equations. It is essential to witness how teachers may apply their organisational skills of ideas against curricular prescription, which might limit their autonomy.

Approach 4: Making links between modes of representations

The multimodal nature of scientific knowledge is central to this theoretical approach. Lemke (1998) notes that Science is not only made up of technical verbal language, but also involves modal language that includes graphical, mathematical, diagrammatical, chemical equations, pictorial, and some other different representations. The fact that these media representations illustrate scientific knowledge makes the modal language more valuable for conceptual comprehension. The ability of a teacher to choose a particular modal representation and make appropriate links between different modes of representation enhances conceptual understanding (Scott et al., 2011)

For an in-depth understanding of electrolysis, redox reactions and solution Chemistry requires learners to confidently move between modes of representations such as word equations, chemical equations and balancing chemical and ionic equations. Scott *et al.* (2011) suggest that the teacher must help learners in moving between different modalities of representation to facilitate processes of link-making by learners. To show conceptual understanding learners are supposed to be able to make their links in their mental functions.

Approach 5: moving between different scales and levels of explanation

Approach five informs the teacher about three levels of explanations fundamental to the scientific body of knowledge, which are macroscopic, microscopic, and symbolic. Teachers must be aware of these three levels and should organise learning material in such a manner that learners can make links between the content of Science and each level (Scott *et al.,* 2011). It is of importance that learners can use the macroscopic, microscopic, and symbolic representations for the scientific conceptual comprehension (Chandrasegaran, Treagust, & Mocerino, 2008).

Scott *et al.* (2011) describe the three levels as follows: macroscopic representation is the visible and tangible Science phenomena; microscopic representation is the particulate level of matter that is made up of invisible entities such as atoms, molecules and ions; symbolic representation comprises of an array of pictorial representations of molecules, ions, compounds, e.t.c. Learners find it difficult to move between these different levels of representations (Scott et al., 2011). Hence, the teacher needs to organise the learning material carefully so that learners conceptualise the concepts being discussed.

For Scott *et al*. (2011) and Chandrasegaran, Treagust, and Mocerino (2008) the microscopic and sub-microscopic levels are one and the same thing. In this research, the term sub-microscopic level is used and is described as the theoretical level or particulate level that is used to describe the movement of electrons, molecules, particles, atoms, anions and cations, with a gaseous, liquid and solid phase. The sub-microscopic level can be presented to learners using modes of representations such as diagrams, pictures, models, videos or animations. To show an understanding of scientific concepts a learner must be able to simultaneously refer to the three scales of representation (Scott *et al*., 2011). That is, the learners must be able to describe what is seen at the macroscopic level using the events taking place at the microscopic level and be able to represent that in symbol form.

Gabel (1993) in her study on teaching about the particulate nature of matter using symbolic, macroscopic, and microscopic found out that learners who were taught in more than one level of explanation achieved higher scores than those who received one level of scale of explanation. Johnstone (1991) argued that natural sciences could be taught using the triangle of levels of thought as shown in the diagram below.

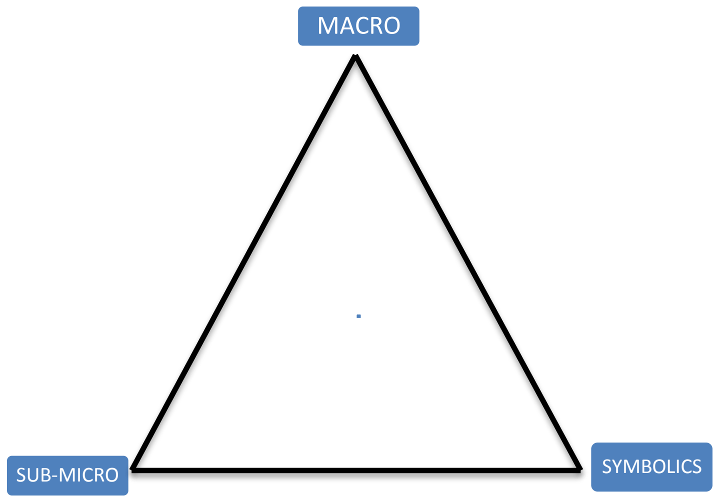


Figure 2.3: Triangle of levels of thought (Adopted from Johnstone (1991))

The corners of a triangle can represent the triangle of levels of thought, as illustrated in Figure 2.3 above. The macro and the tangible involve the observable and sensory phenomena. The micro (sub-microscopic) includes atoms, molecules, ions, and other species. Whereas the symbolic or mode of representations involves formulas, equations, diagrams, mathematical equations, pictures, and models, videos, animations and graphs (Bradley, 2014; Jaber & BouJaoude, 2012; Johnstone, 2000b). It is vital to integrate these three levels of explanation during teaching for conceptual understanding.

In the teaching of the electrolytic cell, teachers need to carry out the experimental activity (e.g. electrolysis of aqueous copper sulphate with copper electrodes). At the cathode, learners will observe (macroscopic level) the appearance of a brown substance. At the microscopic level, the teacher must be able to represent the movement of ions in the electrolyte using pictures, diagrams, animations, or videos to enable learners to visualise what will be happening at the particulate level. Learners can also be shown or asked to represent half ionic equations at both anode and cathode using chemical equations (symbolic level). However, in practice, teachers barely make explicit the behaviour of invisible particles in their teaching. Devetak, Vogrinc, and Glažar (2009) discovered that on the topic of aqueous solutions learners performed poorly when describing submicroscopic level because when teachers teach concepts at the macroscopic level, they did not explicitly elucidate the behaviour of particles at this level. For learner conceptual understanding, all three levels, that is, symbolic, macroscopic and sub-microscopic, should be made explicit to the learner during the teaching and learning process.

Approach 6: Analogical link-making

Scott *et al.* (2011) do not fully encourage the use of analogical link-making as an approach in the pedagogical link-making to support knowledge building. Scott *et al.* (2011. p. 12) say that “we see analogical link-making say slightly different in status to the other five approaches in that it is not an essential prerequisite for developing a deep understanding of an area of Science.” They are not fully embracing the notion of analogies and its ability to foster knowledge building and conceptual understanding. However, they included the approach as necessary for knowledge building due to the acceptance of the use of analogies in the teaching of Sciences. Hence, they say, "…given the prevalence of the use of analogies in Science, in both contexts of the teaching and learning Science and Science-in-making, we are clear that analogies need to be taken as one of the fundamental approaches …" (Scott *et al.,* 2011. p. 12). Duit (2016) also warns teachers when using analogies for teaching and argues that they may bring conceptualisation of knowledge in learners but if not well chosen and when their shortcomings are not explained to learners, they may propagate the development of alternative concepts.

The teacher must make links through interactions at the social plane for the learners to be able to comprehend scientific knowledge at a personal level. The principles of social constructivism will be discussed later under the theoretical framework. Some of the social constructivist features of knowledge building overlap with pedagogical link-making to promote continuity.

2.7.2 Pedagogical link-making to promote continuity

The second form of pedagogical link-making involves making connections between concepts that have been taught over different time scales (Scott *et al.*, 2011). The Science curriculum or any other curriculum is covered over a period and for the FET phase over three years from Grades 10 to 12. During teaching and learning activities, concepts must be linked to other related concepts that have been covered in the past or to be covered in future. The teacher must maintain the scientific story of a particular concept by making links between interrelated concepts (Scott *et al.*, 2011). Alexander (2008) argues that teaching episodes must be accumulative of related concepts.

As teachers keep track of concepts' interrelatedness over different times, emphasis should also be placed on conceptual coherence. Alexander (2008) argues that coherent lines of thinking are the product of concept building by both teachers and learners, which means that in the classroom, it is not only the teacher's responsibility to make links between concepts. Instead, the teacher should point to the connections and help learners work on them on a social plane. Scott *et al.* (2011) identified two approaches to promote continuity, and these are to develop the scientific story and to manage or organise time.

Approach 1: to develop the scientific story

The focus of this approach is to develop a scientific story from learners' substantive content of the lesson through classroom participation. Mortimer and Scott (2003, p. 19) define the progression of the scientific story as "providing a commentary on the unfolding scientific story, to help learners follow its development and to see how it fits into the wider Science curriculum." The development of a scientific story is attributed to the ability of the teacher to link concepts in current lessons with subsequent lessons using learners' previous knowledge. Scott *et* al. (2011) argue that links can be made during the lesson through recaps and elicitations.

The link to develop scientific story approach has three categories, namely, macro, meso and micro (Scott *et* al., 2011). Macro entails continuity links made on the extended time scale (months and years) involving teaching across different chunks of the Science curriculum. Meso entails continuity links made on an intermediate time scale (days and weeks) involving referencing of concepts within a lesson sequence. Micro entails continuity links made on the immediate time scale (minutes or within the lesson), involving referencing of concepts/events within a lesson.

In Chemical change, on the topics under consideration in this research, linking Solution Chemistry or Redox Reactions with Electrolytic Cells is macro-linking, time separated by years. Meso-linking will be, for example, linking concepts of the subsequent lesson of redox reactions such as oxidation numbers, electron transfer and balancing of equations. When the teacher makes elicitations about full or half-ionic equations during balancing of the equation will denote micro-linking.

Approach 2: managing/organising

This approach focuses on the aspects of the ability of the teacher to organise and manage working time between activities within a lesson. The organisation of substantive content takes place on the micro scale when the teacher gives time frames for particular tasks to be completed within a lesson (Scott *et al*., 2011).

The approach encourages the teacher to plan and during the lesson to take command of the transition of learners from one activity to the other. Time plan must be done for the duration of group works, experimental activities and class discussions, e.t.c.

2.7.3 Pedagogical link-making to encourage emotional engagement

Scott *et al*. (2011) describe pedagogical link-making to encourage emotional engagement as the ability of a teacher to make links during the teaching-learning process to boost a constructive emotional response from learners. The attitudes of learners emanate from feelings and emotions. Hence, there is need to investigate teacher-learner and learner-learner relations during the lessons. In this study, much emphasis will be on how the teacher encourages emotional engagement in the classroom.

A significant factor in teacher-learner interaction in the classroom pertains to the teacher's ability to cultivate an emotionally supportive classroom climate (Reyes, Brackett, Rivers, & Salovey, 2012). Rosiek (2003) reiterates the importance of the teacher's practical knowledge about the need to emotionally engage learners. He argues that emotions have a prominent presence in the learning process because there is no learning when ideas and knowledge are not translated into emotion and interest. Thus, the pedagogical link-making as a teaching approach seeks to investigate how the teacher-learner and learner-learner interactions contribute to the emergence of different feelings and emotions in the Science classroom (Scott *et al.*, 2011). Scott *et al*. (2011) suggest two ways by which teachers can foster positive emotional engagement in the classroom. The 2, making links through substantive content lessons and using generic approaches are explained in the next section.

Approach 1: Addressing Substantive Content

In this approach, the teacher's role is to engage and encourage the linking of positive emotional engagement and the substantive content of the lessons (Scott et al., 2011). Scott et al. (2011) argue that substantive content entails that the teacher makes links between the developing story of the lesson and learners, whether individuals, pairs or groups. That can be attained in two ways, that is, by making links between a specific point of view to the learner who raised it and by making the concepts relevant to learners. Firstly, the role of the teacher is to credit those learners contributing in a class by ascribing learners' names to notions or ideas they have uttered during discussions. As the teacher values the learner's voice, it positively influences his/her self- esteem. If the teacher manages to satisfy the learner's need for self-esteem, it leads to feelings of confidence, worthiness, competence, and appropriateness of being valuable and is essential in the classroom. For example during the discussion on the dissolving of salt, a learner by the name of Noxolo asserts that solutes do not disappear in a solvent. The teacher will then refer to this assertion or contribution as Noxolo's idea and the teaching and learning will then be developed on that assertion. Mortimer and Scott (2003) argue that such an approach ensures that classroom discourse is rich with interactions that ascribe particular scientific point views of specific individuals, which motivates learners and raise their self-esteem.

Secondly, Scott et al. (2011) argue that emotional link-making between learners and the substantive content of the lessons is improved through the selection and staging of a memorable event, which helps to engender the positive responses of the learners. The Science event must be striking and very special that it will be significant to learners. It involves the teacher asking learners to predict the outcomes of this remarkable, memorable activity before it is executed. Wigfield and Cambria (2010) argue that asking learners to predict the expected results of the activity draws learners' attention and arouses their interest as well. Even though the learner's prediction is incorrect, the approach demands that learners explain why their prediction was inaccurate that deepens learners' conceptual understanding (Scott et al., 2011; Tchoshanov et al., 2017). The excitement and expectant behaviour of learners and the explanation demand before and after the activity encourage emotional and intellectual engagement respectively (Guthrie et al., 2006). Scott et al. (2011) encourage that the memorable or striking event must be relevant to the learners for it to be effective.

Approach 2: Generic Approaches

The generic approaches focus on teachers' use of praise and encouragement to learners when they participate in class (Scott et al., 2011). The approaches involve identifying learners by names and praising them for the contributions made. Generic praises such as, very good, well done and fantastic are discouraged by Scott et al. (2011) as they do not differentiate the value and quality of answers from learners. Reyes et al. (2012) argue that learner achievement is enhanced when teachers encourage positive interactions as they provide learners with mental space and confidence for learning to occur.

2.8 Conclusion

This literature review chapter discussed constructivism and social constructivism as the theoretical foundation upon which the analysis presented in this thesis is embedded. The nature of the spiral nature and its feature was also highlighted in detail from a social constructivist approach. Furthermore, the literature on teaching strategies that foster meaningful learning and the importance of a coherent and hierarchical subject content was reviewed against the disadvantages of rote learning. Concept mapping was presented as one instrument that can be used to deduce the coherence and nature of the structure of chemistry content as it taught by teachers. Lastly, the chapter discussed in detail forms, approaches and tools as embodied in the analytical framework, the pedagogical link-marking. However, the last form of pedagogical link-making to promote emotional encouragement was reviewed only to present the full framework but was not considered in data collection of this research. The next chapter will now focus on the methodological design of the inquiry.

CHAPTER 3

Research Design and Methodology

3.0 Introduction

In this chapter, I will outline the philosophical assumptions that underpin this qualitative research or inquiry and its design. Qualitative research is where an observer (researcher) studies meanings constructed by participates on a phenomenon in their natural setting (world) (Denzin & Lincoln, 2013; Hoepfl, 1997; Merriam, 2009). I was a spectator observer (Patton, 2015) who visited and gathered data from teachers in their natural classroom settings. I sought to understand the teacher's teaching approaches in their context-specific settings (Hoepfl, 1997) without intentionally changing any conditions of their world.

In the field, I was guided by the interpretivist paradigm. Kuhn (1963) described a paradigm as a summary of the enquirer's beliefs on their efforts to construct knowledge. Over the years, this notion of paradigm has changed to include outlines and practices of the researcher in the field. Guba (1990) describes a paradigm as an interpretive outline, a basic set of beliefs that guides the researcher's actions. It (paradigm) is also regarded as a systematic set of beliefs accompanied by methods (Scotland, 2012). However, in this research, a paradigm is viewed as a basic set of human construction beliefs that outlines the worldview of the enquirer. These beliefs are embedded in the three axioms encompassed by the paradigm which are epistemology, ontology and methodology (Scotland, 2012).

Epistemology is the process of thinking about the relationship between what is known and what is seen (Lincoln, Lynham, & Guba, 2013). It has to do with how knowledge is constructed, attained and communicated (Scotland, 2012). Cresswell and Poth (2018) argue that epistemology speaks to reality as socially co-constructed and shaped by individual experiences of the researcher and the participants. My epistemological assumption was that knowledge is socially constructed among teachers and learners. Epistemology critically values the duration of the researcher in the field gathering data. The longer the researcher stays in the field, the more they gather first-hand data about the phenomenon (Cresswell & Poth, 2018). In this study, I stayed in the field for a maximum possible time as determined by the specific duration of the topics understudy; Reactions in aqueous solutions, Redox reactions, and Electrolytic cells.

These topics predetermined the "fixed" timeframe I was in the field. The exact duration was according to the planning, pace of the teachers and the factors that affected the teachers in their natural environment of work. For example, Masutha had to cut short his first lesson to a mere 10 minutes due to the visit of the department of education officials who had come to motivate Grade 12 learners about eminent imminent examinations.

Ontology refers to nature of reality; it asks the question about the being of humankind, and its belief is in multiple realities (Cresswell & Poth, 2018; Grant & Giddings, 2002; Lincoln et al., 2013). However, these multiple realities are relatively subjective and constructed by individuals. Therefore, to understand how meaningful learning is enacted or lack thereof in the classroom, different individual teachers from different naturalistic settings were involved in the research. I assumed that the more individual teachers are involved, the more I gather about the factors that affect learner conceptual understanding in the classroom.

The methodology has to do with knowing the world and knowledge of it (Denzin & Lincoln, 2013). In the quest of knowing the world, the qualitative interpretivist's procedures are logically inductive (Cresswell & Poth, 2018). The methodology is defined as a strategy of choosing and using particular methods in the gathering and analysing of data (Scotland, 2012). It is the means of gaining knowledge about the world (Lincoln et al., 2013). It (methodology) is a blueprint or detailed roadmap describing the processes of data gathering and its analysis. Denzin and Lincoln (2013) give case study as one of the methodologies that can be used to collect data from the world. In this research, to have an in-depth understanding of the problem of conceptual understanding of the electrolytic cells and its fundamental concepts, a multi-case methodology of five teachers was adopted. In this study, the methods employed to gather data were lesson observations, document analysis and teacher interviews. Social constructive paradigm embeds grounded theory as the basis of data analysis. However, in this study pedagogical link-making was used as the analysis guideline as it explicitly accounts for an ideal social constructive classroom where meaningful learning can be achieved.

As the project is a qualitative case study, the discussion on the nature of the case will be discussed first. This followed by an in-depth discussion on the methodology that was used to gather data including sampling procedures. A snapshot of how results will be analysed is captured in this chapter. The ethics procedures that were followed in this study are also presented in this chapter.

3.1 Case Study

The case study as a qualitative inquiry approach has been clouded by uncertainty in the past years. Merriam (2009) posits that the confusion emanates mainly from the 'case' and it needs to be understood from the onset. Mertens (2005) defines the case as an instance, and Stake (1978) describe it as a constituent member of a target population. Miles and Huberman (1994) view it as a singularity that takes place in a bounded framework. Merriam (2001, p. 27) defines a case as "… a thing, a single entity, a unit around which there are boundaries." The case needs to be clear and its boundaries clearly defined for it to be relevant for research.

The case must be a bounded system of interest (Stake, 1978) and its characteristics are defined by the delimitations of the study (Merriam, 2001). I regard the bounded system as an enclosed parameter; whatever is in it is relevant to the study, while what is outside of the parameter is not to be investigated. McMillan and Schumacher (2010) describe the bounded system as being unique about time, location and characteristics of participants.

A case study refers to a researcher who undertakes a comprehensive investigation of a sole subject or group or phenomenon (Borg & Gall, 1983). More precisely, it is an in-depth, holistic description and analysis of a single unit in a natural setting (McMillan & Schumacher, 2010; Merriam, 1998; Opie, 2004). Opie (2004) explains case studies as exhaustive accounts and investigations of a single unit or bounded systems such as a discrete, program, event, group, or community. In this study, there is no controlling of any factors to influence the participants. Instead, the research was carried out in the natural context of participants.

McMillan and Schumacher (2010) identify three types of case studies that include intrinsic, instrumental and collective cases depending on the focus of the research. The intrinsic case study focuses on a case itself that is unique. The instrumental case is that which provides insight into a specific issue, and common cause is that which consider a combination of different cases in one study (McMillan & Schumacher, 2010). Contrary to McMillan and Schumacher (2010), Borg and Gall (1983) identify five types of case studies, which are historical case studies of organisations, observational case studies, oral histories, situational analysis and clinical case studies.

Merriam (2001) identifies the different types of cases regarding disciplinary orientation, the overall intent (or function) and multiple case studies. Disciplinary oriented case studies include ethnographic, historical, psychological, and sociological. While descriptive, interpretive (analytical) and evaluative represents the overall intent case studies. Multiple case studies are generally referred to as common case studies, cross-case, multi-case or multisite studies, or comparative case studies. Multiple case studies involve the collection and analysis of data from several cases (Merriam, 2001). Other definitions and what each case study entails are beyond the scope of this project. Nevertheless, descriptive case studies are briefly described, as they are the focus of this research together with multiple case studies.

A descriptive case study calls for a comprehensive account of the phenomenon understudy while the evaluative case study encompasses description, explanation and judgement (Merriam, 2001). In this project, multi-case studies were employed through depth understudying of five different teachers at five different schools, teaching the topics: Reactions in aqueous solutions Grade 10, Redox reaction Grade 11, and Electrolytic cells Grade 12 under Chemical Change. The resolve of the case studies is to evaluate how teachers teach for conceptual understanding of the mentioned abstract chemical concepts.

3.2 Unit of Analysis: ‘The Case’

The study took place in three different districts namely in Gauteng East, Johannesburg Central and Ekurhuleni North, with five participating teachers drawn from five different schools. The teachers were observed teaching the topic of Electrolytic cells and their underlying concepts from Grades 10 to 12. The Chemical change has been singled out in Chapter 1 to be the pertinent topic as exhibited in the analysis of Grade 12 final results. The fact that it contributes more marks in the Physical Science paper 2 Chemistry section makes it an essential section for the improvement of results if learners are taught for comprehension. The study focussed on how teachers taught the topic of the electrolytic cell and its critical concepts under chemical change for conceptual understanding.

This study does not concentrate on the mathematical aspect found in the chemical change as a learning area. The calculation of standard electrode potentials cells and mole ratios were not considered in the study. Also, the case did not seek to evaluate learners' performance in an examination; hence no assessments were evaluated. The study concentrated on how teachers taught the topics under study, whether they taught for conceptual understanding or not. Therefore, the focus was on the teacher. Classroom interactions were evaluated to understand the impact of teachers' chosen strategies in teaching for conceptual understanding.

3.3 Sampling

Sampling is defined as the means of selecting a given number of participants from a target population (Borg & Gall, 1983; Mertens, 2005). Merriam (2001) asserts that sampling comprises a selection of a research site, time, participants, and events. Sampling can also be viewed as a method used for the selection of a given number of participants from a target population. Borg and Gall (1983) defined the target population as inclusive of all members of an actual or hypothetical set of people, events or objects to which generalisations of the research outcomes can be made.

The Gauteng province was chosen as a sample of convenience because I lived and studied in the province. Convenience sampling was preferred based on the notion of time, expense, geographical location, readily available sites and participants (Merriam, 2001). With the help of the district subject specialist, all Physical science teachers were invited to a debriefing meeting about the project on a Saturday. Only 15 teachers out of a possible 45 invited teachers attended the meeting. Only five teachers volunteered to participate in the research and others could not due to different reasons. The primary reason why most of the teachers could not participate was that the targeted topics were being covered during the third term, which was a crucial term for most Grade 12 teachers. Hence, some teachers felt that in most cases principals would not permit them.

The sample of teachers (n = 5) consisted of two females and three males (see Table 3.1). The teachers were pseudo-named Mrs Meyer, Mr Masutha, Mr Zulu, Mrs Ndebele and Mr Johannes. The average teaching experience of the five teachers was 19 years. Accidently, most of the teachers had a firm background in Chemistry, and the study involved the teaching of topics in chemistry. Hence, the subject matter knowledge of the concepts was assumed to be a constant variable. Mrs Meyer obtained her two first qualifications, National diploma in analytical chemistry and Bachelor of Technology majoring in Chemistry with the Vaal University of Technology. Due to difficulty in getting a job of her trade, she ventured into teaching and obtained a postgraduate certificate in education with the University of South Africa (UNISA) in Senior Phase and Further Education Training (Physical Sciences). Mrs Ndebele possesses a national certificate in Mechanical Engineering, a diploma in education majoring in Physics Chemistry and Biology with the University of Zimbabwe (UZ), and an honours degree in Psychology with UNISA. She had 15 years of experience in the teaching of Physical Sciences.

Name (Grade)	Gender	Qualification	teaching experience	School Name	Type of School
Meyer (11 & 12)	Female	National Diploma in Analytical Chemistry. BTECH Chemistry PGCE senior phase & FET science.	11	A	Suburban boarding
Masutha (12)	Male	BSc (Chemistry & Biochemistry), Graduate Certificate of Education, BSc Honours (Ed), MSc (Ed),	24	B	Suburban weekly boarding
Zulu (10)	Male	BSc Chemistry Education, ACE Maths & Physical Science,	25	C	Township
Ndebele (11)	Female	National Certificate in Education. Mechanical Engineering. Dip. Ed (Sciences), Bed Honours (Psych)	15	D	Township
Johannes (10)	Male	Dip Ed, Bed Chemistry, Bed honours (Physical Science), MSc Education	18	E	City

Table 3.1: Summary of the Demographic of Teachers

Mr Zulu was the most experienced teacher in the sample. He obtained his Bachelor of Science education degree majoring in Chemistry in Cuba. He further did his Advanced Certificate in Education (ACE) in Mathematics and Science education with the University of Johannesburg and obtained another ACE in Physical Sciences with the University of the Witwatersrand (Wits). Mr Johannes has 18 years of experience, obtained his Diploma of Education (Science Education) and Bachelor of Education (Chemistry) with UZ. He further obtained his Bachelor of Education honours with Wits and graduated with his Master of Science Education with the same university in the year after collecting data. Mr Masutha, with 24 years of experience, obtained his Bachelor of Science (BSc) Majoring in Chemistry & Biochemistry and Graduate Certificate of Education from UZ. He further obtained two educational qualifications from Wits University, namely, BSc honours in Physical Sciences Education and MSc Science Education.

All the five teachers were teaching Physical Sciences at the Further Educational Training (FET) Phase in their various schools. Mrs Meyer taught two classes of Grade 11 and three classes of Grade 12, and she was observed teaching one class per grade. The Grade 11 class had 21 learners (15 girls and 6 boys), and the Grade 12 class had 17 learners (12 girls and 5 boys). Mrs Ndebele taught three classes of Grade 11s and one class of Grade 12; she was observed teaching grade 11 with 37 learners (24 girls and 13 boys). Mr Zulu taught two Grade 10 classes and three Grade 12 classes. He preferred to be observed teaching Grade 10 class of 40 learners (26 girls and 14 boys) as he was catching up with the Grade 12 classes. Mr Masutha had three Grade 12 classes and two Grade 11 classes and was observed teaching a grade 12 with 23 learners (16 girls and 7 boys).

Lastly, Mr Johannes was teaching three Grade 10 classes and two Grade 12 classes. The principal of Mr Johannes requested that the lesson observation be done with the Grade 10 as he wanted the Grade 12 learners to concentrate on the preparation of the preliminary examinations. The other three teachers did not choose classes to be observed. Instead, I had to find classes which were not clashing with those who had specific grades they volunteered to be observed teaching.

I obtained teachers' timetables and used them to draw an observational schedule. The curriculum of the Gauteng Department of Education is arranged in such a way that each topic per grade is covered at the same time across the province. Therefore, it was necessary to design a schedule that did not clash to observe all lessons on each topic per grade for the different teachers. Table 3.2 below summaries the number of lessons observed per topic in each grade per teacher.

Table 3.2: Lesson observation and interview schedule

Teacher/ (Grade)	Topic	Time of observation	No. of lesson	Duration of the lesson (mins)	Actual time Observed (mins)	Interview (mins)
Johannes (10)	Reactions in Aqueous Solutions	Last 2 weeks of August	2 + 1 double	45 (180)	35 + 37 + 85 =157 (180)	15
Zulu (10)	Reactions in Aqueous Solutions	Last 2 weeks of August	2 + 1 double	40 (160)	160 (180)	12
Ndebele (11)	Redox Reactions	Last 2 weeks of September	3	60 (180)	180 480	16
Meyer (11 & 12)	Redox reactions	Last 2 weeks of September	2 + 1 double	45 (180)	180 480	21
	Electrolysis	First week of August	2 + 1 double	45 (180)	180	
Masutha	Electrolysis	First week of August	2 + 1 double	45 (180)	180 (180)	19

As depicted in Table 3.2 above, observations lasted a week for each grade. Two teachers were observed per week per grade teaching the same topic in their various schools. After classroom observation, each teacher was interviewed. The interviews were done after school so that lessons will not be disturbed. Mr Johannes was only interviewed after weeks from last observed lesson. This is because he was busy preparing Grade 12 learners for their preliminary examinations. However, other participants were interviewed after a week when I had gone through each of the video and audio recordings to conceptualise areas of interest.

Before my interaction with the teachers, three of the five teachers were exposed to the teaching strategies that foster conceptual understanding such as Pedagogical Link-making, Pedagogical Content Knowledge (PCK), Indigenous Knowledge, e.t.c.

Mr Masutha and Mr Johannes had gone through the courses of Learning theories and the Learning and Teaching of Science that included such teaching strategies in both Honours and Masters' Courses, respectively. In her PGCE at UNISA, Mrs Meyer was exposed to teaching strategies that foster effective mediation of teaching and learning in the Educator as Mediator of Learning module. She was involved in research by one of the Witwatersrand Masters' student's research that used pedagogical link-making as an analytical tool in the teaching Chemistry topics. The other two teachers alluded to the fact that they had these strategies were only familiar to them through discussion with colleagues at workshops. Hence, it was necessary to have a little debriefing of 1 hour to unpack how teaching strategies, mainly, PLM works since it was going to be used as an analytical tool.

3.3.1 Schools

I visited each of the five schools where the teachers were working before the beginning of lesson observation to seek permission from principals as well to facilitate filling of consent forms by learners and their parents. The status of each of the five schools is shown in Table 3.3.

Table 3.3: School demography

Name of School	Location	Type of School
A	Suburban	Former Group C
B	Suburban	Former Group C
C	Township	Satellite
D	Township	Old
E	Suburban	Built after independence

There were two former group C schools (A and B), and School D was a former disadvantaged school as shown in Table 3.3. School C was a satellite school, and school E was built soon after independence in 1994. Each school had a standing laboratory except school C which did not even have science equipment and relied mostly on borrowing chemicals and equipment from nearby schools. School A had a standing laboratory that was fully equipped with both equipment and chemicals. The teacher had the privilege of using a mobile data projector as well. In School B, the laboratory was well equipped and was used as a homeroom by Mr Masutha. School D as the previously disadvantaged school it got a preference of being turned into a paperless school by the Gauteng MEC for education. It was equipped with smart boards, and the laboratory was under renovation by the time the observations were done at the school. The smart board was installed at school C but was stolen within a few months of installation. School E, though it had a standing laboratory, Mr Johannes used an ordinary class for all his classes as the other teacher was using it as his homeroom.

3.4 Instruments

The instruments used to gather data are discussed in this section: semi-structured interviews, documents and lesson observations.

3.4.1 Observations

In qualitative research, observation guides the researcher toward understanding the case under study in its local or natural setting (Merriam, 2009). Cresswell and Poth (2018) define naturalist observation as a technique that is used to gather ideal and unobtrusive data. This instrument is used to observe first-hand phenomena, events or situations, and when a new opinion is desired (Merriam & Tisdell, 2016). Patton (2015) argues that there are different types of observations, which lies on a continuum range. The two extremes of the continuum are a participatory observer and a spectator observer.

A participatory observer is when a researcher is a full participant. On the other hand, an onlooker or spectator observer is separated entirely from the happenings on the settings (Patton, 2015). On this project, I was an onlooker who tried thoroughly to capture almost all activities in the classroom through video and audio recordings. Each teacher was observed teaching one of the chemical change topics; three lessons per educator.

Table 3.2 shows the number of lesson observations done per teacher. Observation can be vastly subjective and consequently undependable nature of human opinion. Merriam and Tisdell (2016) argue that human nature is very elective and to minimise this weakness all observations were video recorded, and audio recorded. The audio recording device was strapped on the educator, to capture every word that was uttered by the teacher during the lesson. The video also recorded learners' and teacher's interactions during class activities. Transcriptions of video and audios were done and were analysed using the PML analytical tool shown in Table 3.4 below.

3.4.2 Documents

Documents analysis was the other source of data that was used in this research. The written text refers "to a wide range of written, visual, digital and physical material relevant to the study" (Merriam & Tisdell, 2016, p. 162). Silverman (2016) argues that text data influences how we perceive the world and the people in it and how we act and think of them. Stake (1995) explains that documents can be used as a substitute for the proceedings of happenings that I could not observe or interview. They provide evidence of what the participants are doing without being asked by the researcher (Silverman, 2016).

Merriam and Tisdell (2016) identify five types of documents, namely, public records, personal documents, popular culture documents, visual documents and artefacts and physical materials. Public documents are the only type of documents that this research analysed. Merriam and Tisdell (2016) define public documents as ongoing official records of a society's activities. This research focused initially on three documents; namely, the teacher lesson plans, 2014 to 2017 Further Education Training (FET) phase work schedules, and the Physical Science CAPS content document of 2011.

Lesson plans are regarded as public documents despite that they are prepared by an individual, who is a teacher. They are considered public because they must be readily available when asked for primarily by the educational authorities for monitoring teachers' progress in lesson delivery, teaching strategies, time management, and lesson coherence. These facets of a lesson plan and many others are necessary for the propagation of teaching for conceptual understanding in the teaching of science. An analysis of the lesson plan using the PLM analytical tool will entail if the proposed initial roadmap planned by the teacher has been accomplished versus what has been observed or said by the teacher. The analysis will help to ascertain if that proposed roadmap had necessary features that warrant meaningful learning or conceptual understanding during lesson delivery.

However, the lesson plans could not be analysed as only two teachers produced their lessons plans. These were also not analysed as they were not prepared before the lesson but after teaching when I had continuously reminded the teachers of their lesson plans. The other three teachers could not avail of their lesson plans, and they categorically stated that they never use them at all during their teaching. Hence, lesson plans document analysis was not done because I wanted to cheque the planned teaching sequence of concepts against the observed conceptual sequence during the actual teaching.

The Physical Science CAPS content document is the syllabus of or a curriculum statement from which all topics and concepts to be taught for all FET grades are outlined. The work schedules are annual teaching plans drawn from the content document and arrange the topics into teachable units. The topics follow a particular sequence which is already determined for all teachers and should be followed to the dot. The annual teaching plan is used by teachers to report their content coverage progress, and the district officials use it as their monitoring tool to check syllabus coverage by the teachers.

The Department of Basic Education (BDE) assert that the topics and concepts adopt the notion of spirality. The qualitative document analysis research methodology was engaged in analysing the sequencing of in the Physical Science CAPS content document and the work schedules from Grade 10 to 12. The analysis was only done for the topics Reaction in aqueous solutions (Grade 10), Redox reactions (Grade 11) and Electrolytic Cells (Grade 12).

The pedagogical link-making to promote continuity particularly the approach to develop the scientific story (Scott et al., 2011) was used to analyse if indeed CAPS follow the spiral approach. The link to develop scientific story has three categories namely; macro scale (Concepts progression across grades) and meso (Arrangements of topics within a grade) and micro (concepts linked within the lesson). However, only macro and meso were used to scrutinise content arrangement in the curriculum.

3.4.3 Semi-Structured interviews

There are different types of interviews in qualitative research. Patton (2015) identifies 12 different types of interviews. Merriam and Tisdell (2016) argue that structure and theoretical stance can classify interviews, whereas focus group and online interviews are identified as standalone types of interviews. The structured interviews which Merriam and Tisdell (2016, p. 109) identify as standard and can be placed on a continuum that starts "from highly structured, questionnaire driven interviews to unstructured open-ended, conversational formats". The semi-structured interview is at the centre of the continuum, and it is the instrument that was used in this study.

The closed or highly structured interview comprises of detailed questions that are formulated beforehand to gather especially demographic data. Structured interviews seek accurate responses to specific questions and assume that participants will interpret questions in the same manner (Leech, 2002). The primary weakness of the structured interview is in its adherence to rigidly predetermined questions that prevent the participants from presenting their views about how they understand and perceive the world (Merriam and Tisdell, 2016). This study did not pursue the structured interview as the research seeks to access how teachers understand and perceive teaching for conceptual understanding in the science classroom.

Open-ended structured interview lies to the other extreme of the continuum and is fundamentally exploratory, and the researcher would be seeking to know an area he or she is not familiar with (Merriam and Tisdell, 2016). Silverman (2016) notes that the participant must be given freedom to talk to collect rich data. The dangers of open-ended question are when the researcher assumes that he or she is familiar with the topic and ask wrong questions that compromise the validity of the data gathered (Leech, 2002). A mix of highly structured and open-ended interview was preferred in this research.

Kvale (2008, p. 10) describes a semi-structured interview as an “attempt to understand the themes of the lived daily world from the subjects’ perspectives”. Merriam and Tisdell (2016) indicate that this type of interview allows the researcher to respond to emerging worldviews and explore new ideas from the participant’s perspective. Semi-structured interview seeks to comprehend the lived practices of the participant and obtain comprehensive explanations of the lived phenomenon to develop thematic interpretations. It is guided by a protocol of questions involving issues to be explored and does not follow the exact wording of the interview schedule. Leech (2002) argues that only topics or sub-topics are asked contrary to a closed structured interview that seeks answers to specific questions.

In this research, the participants were questioned on how they used specific skills in fostering conceptual understanding in their teaching. The questions were sought to explore reasons and explanations of actions taken by participants during lesson observations. Bassey (1999) notes that this type of interview permits participants to offer thorough, impulsive explanations of their practices, opinions and attitudes as well as evidence supporting their actions. Through its flexibility and room for probing semi-structured interview allowed the participants’ generation of detailed, useful data for the study.

Probes are follow-up comments or questions asked by the interviewer after sensing significant contribution that has substance to learn from. Patton (2015) argues that probes are appropriate follow-up questions that seek greater depth and detail. They are highly unpredictable and always depend on how the initial question is answered by the participant (Silverman, 2016). Silverman (2016) further states that bunched utterances such as yes, ok and huh are good alternates of probes. I employed these probes, and the participants provided detailed accounts of their encounters. The pre-planned main framework of questions was not rigidly followed.

An interview protocol consisting of eight questions was sent to participants a couple of days before the interview for them to know and familiarise themselves with the goals of the interview. Stake (1995) argues that the researcher should arrive at the interview venue with a short list of issue-oriented questions, which might be given to the participant as well. The primary function of the interview protocol (appendix D) is to ensure that all pre-determined relevant topics are covered during the interview (Patton, 2015).

The interview protocol consisted of eight questions that were derived from the PLM analytical tool (appendix D). The questions also sought to feel the gap(s) of what observation could not cover and verify what was observed. Question 1 asked the participant to evaluate the impact of the teaching strategy according to his or her perception. Questions three to six are verification questions of what was observed in the classroom. Questions 7 and 8 are opinion seeking question about the effectiveness of the strategy.

3.5 Data Analysis

The pedagogical link-making to promote continuity and to support knowledge build by Scott et al. (2011) was used to analyse the collected data. As mentioned in Chapter 2 pedagogical link-making consists of three forms which include the two forms discussed above including pedagogical link-making to promote emotional engagement. However, in this study, the latter is not considered. I had to create my own coding to handle the data emanating from the data which is not part of the original idea of Scott et al. (2011).

3.5.1 Coding

According to Friese (2013), the word code in qualitative research refers to small pieces of text that are used to reference other portions of text data. In this research, the word code will be used to mean a set of letters and/or numbers that denote particular phrases found in the text. The purpose of the codes is to identify the occurrences of selected phrases for tallying and finding relationships if any between certain phrases. They are used as sorting devices to generate sets of related information parts for the purposes of comparisons (Friese, 2013). In this research, coding was predetermined as an existing analytical framework was used to analyse data. The set of numbers and letters was not derived from the original analytical tool but was my own initiative to work with small pieces of text during the analysis of results.

The preliminary coding based on the analytical framework developed by Scott, Mortimer and Ametller (2011) was done in the following manner. The three main ideas (forms) in the pedagogical link-making, which are to support *knowledge Building*, to *promote continuity* and encourage *emotional engagement* were give codes of KB, PC, EE, respectively (see Table 3.4). However, due to the stipulations of the length of the thesis, the form to encourage emotional engagement was not included in the analysis of the thesis. Each form of pedagogical link-making had different approaches in it. These approaches were used to "identify specific *pedagogical tools/strategies* observed in the classroom to support link-making" (Scott, Mortimer, & Ametller, 2011, p. 4). The pedagogical approaches were designated numbers according to the number of approaches in each form or the main idea of PLM, see table below.

Table 3.4: Pedagogical Link-making Approaches, Tools and Codes

PML Form	Approaches	Pedagogical tool	Codes	Frequency
To promote knowledge	Making links between every day & scientific ways of explaining	Integration	KB1-1	
		Differentiation	KB1-2	
	Making links between scientific concepts	Linking scientific concepts	KB2	
	Making links between scientific explanations and real-world phenomena	Simple phenomena	KB3-1	
		Complex phenomena	KB3-2	
	Making links between different scales & levels of explanation	Micro	KB4-1	
		Macro	KB4-2	
		Symbolic	KB4-3	

building	Making links between modes of representation	Pictorial	KB5-1	
		Diagrammatic	KB5-2	
		Chemical equations	KB5-3	
		Mathematical expressions	KB5-4	
		Videos	KB5-5	
		Tables	KB5-6	
		Models	KB5-7	
		Graphical	KB5-8	
	Making links between analogous cases	Analogies	KB6	
To promote continuity	To develop the scientific story	Macro-scale	PC1-1	
		Meso-scale	PC1-2	
		Micro-scale	PC1-3	

For example, the form pedagogical link-making to promote knowledge building has six approaches, which were numbered one to six with codes KB1 to KB6. The first approach: Making links between every day and scientific ways of explaining (KB1) has two pedagogical tools, which were numerically numbered and designated the codes KB1-1 (Integration) and KB1-2 (differentiation). Between the two forms under consideration, there are seven approaches and 20 pedagogical tools. The 20 pedagogical tools were the ones that were used to analyse the gathered data from the classrooms and the documents.

3.6 Ethics

Permission was sought from the university and the department of education to carry out this research in the Ekurhuleni North, Johannesburg East and Gauteng East Educational Districts of Gauteng province. Upon receiving the protocol number, I administered the consent forms and information sheets to the principals, the teachers, learners and parents. The information sheets sought permission to be in schools to interview, video record and audio tape the teachers, for different lessons from Grade 10 to 12. Permission to audio record and videotape learners was sought and granted. The anonymity of the five participating teachers and their learners was guaranteed as no other person other than my supervisor, participating teachers and I had access to video and audio recordings.

Where other colleagues were given access to transcriptions to validate my findings, pseudo names were already assigned to all those who were captured in the transcriptions. Hence, all names except for the district and province are factious and had no link whatsoever to the real participants. Participation was voluntary, and participants were given the freedom to withdraw any given time without victimisation of any form. However, there were no withdrawals from any teacher, and there were no learners who resented participation in the project.

3.7 Rigor

Morse, Barrett, Mayan, Olson, and Spiers (2002) assert that research without rigor is insignificant, fictitious and loses its value. Rigor in research is referred to as a marker of quality sought through data collection techniques (Smith & McGannon, 2017). Reliability and validity are general terms or processes used to describe rigour precisely. Validity denotes the extent to which a method, a test or a research tool measures what it is supposed to measure (Smith & McGannon, 2017).

Opie (2004) argues that validity refers to the relationship between a claim and the result of the data gathering process. Reliability denotes the extent research findings can be repeated (Gibbert, Ruigrok, & Wicki, 2008). It encompasses the way data has been gathered and how it has been analysed. It is a property of the whole process of data gathering rather than a property solely of the results (Opie, 2004). As I adopted the naturalistic interpretive approach, I will not bore the reader with the issues of reliability and validity in ensuring rigor in this case study inquiry. Bassey (1999, p. 75) argues that evaluation case studies do not substantially comprise cause and effect as in quantitative inquiry, instead “it is a study of a singularity which is chosen because of its interest to the researcher”. Hence, in this research I used credibility and trus2rthiness as purported by Lincoln and Guba (1985), these resemble validity and reliability respectively, in ensuring rigor in quantitative research (Sargeant, 2012).

Qualitative research uses the naturalistic approach in the gathering and analysis of data. The naturalistic approach seeks to understand phenomena in context-specific settings that are in a real-world setting (Guba, 1981). Guba (1981) proposes that naturalistic researchers in pursuit of a trustworthy study should consider four criteria. These are Credibility (confidence in the 'truth' of the findings); Transferability (showing that the results have applicability in other contexts). Dependability (indicating that the findings are reliable and recurrent). Confirmability (a degree of neutrality or the degree to which the results of an inquiry are designed by the respondents and not researcher bias, motivation, or interest) Guba and Lincoln (1985).

In this study, Credibility was ensured by the prolonged engagement with participants, that is I was on the sites for the whole duration of the teaching of each topic per teacher per grade. As indicated in Table 3.2, I observed all the three lessons (2 plus one double) in most cases except for Mrs Ndebele’s school D where all lessons were one hour long. As the research was topic specific, it was unwarranted for me to remain on site when teachers had finished teaching topics that were an understudy. However, I made separate appointments outside teaching time to do individual teacher interviews. Cope (2014) argues that credibility is improved when the experience of the researcher in the form of findings are shared and verified with participants. This form of credibility is known as member checking or participant feedback by Lincoln and Guba (1985), which involves the participation of the participants invalidating the collected data and the analysed results (B. Smith & McGannon, 2017). To enhance the credibility of the data and its findings each participating teacher was given the audio, video and transcripts of the first and third lessons on a memory stick to verify if each transcript was done according to what was recorded. Participants were encouraged to sample portions of their choice in the video or audio recordings to verify and correct where necessary. After an analysis of the preliminary results, participants were also given analysed results to validate if they concurred or objected with the findings. For example, when answering the research question, to what extent do teachers use knowledge building strategies in the teaching of electrolytic cells and its fundamental concepts at senior secondary, level? Participating teachers were given transcripts, tally tables of concepts that were captured in the lesson and concepts maps drawn from the tally tables. They were asked to verify if what was captured on the tally table was all that was reflected in the transcripts and to rectify where possible on the concept maps drawn. Figure 3.1

below shows how member checking, and peer review shaped the concept map for Mr Johannes as his first lesson was analysed.

The first diagram in Figure 3.1(a) labelled KB 2 analysis version 1 researcher was the original concept map that I draw from the tally table of concepts as depicted in Mr Johannes' transcriptions. The diagram in Figure 3.1 (b) labelled KB 2 analysis version 2 teacher, is an example of what the participants added or contributed. As shown in the version 2 (Figure 3.1 (b)) diagrams, Mr Johannes added two concepts to the links that I had not captured. The added concepts were of solute (silver nitrate) and electrons (gaining or losing electrons during the oxidation and reduction reactions. The two added concepts are shown in Figure 3.1 (b) with thick shot arrows. All other four participants did the same, and it should be stated that the exercise took longer (one month) with Grade 12 teachers (Mr Masutha and Mrs Meyer), due the pending preliminary examinations. However, the other three participating teachers managed to finish the exercise in less than two weeks.

(a) KB 2 Analysis Version 3 Researcher

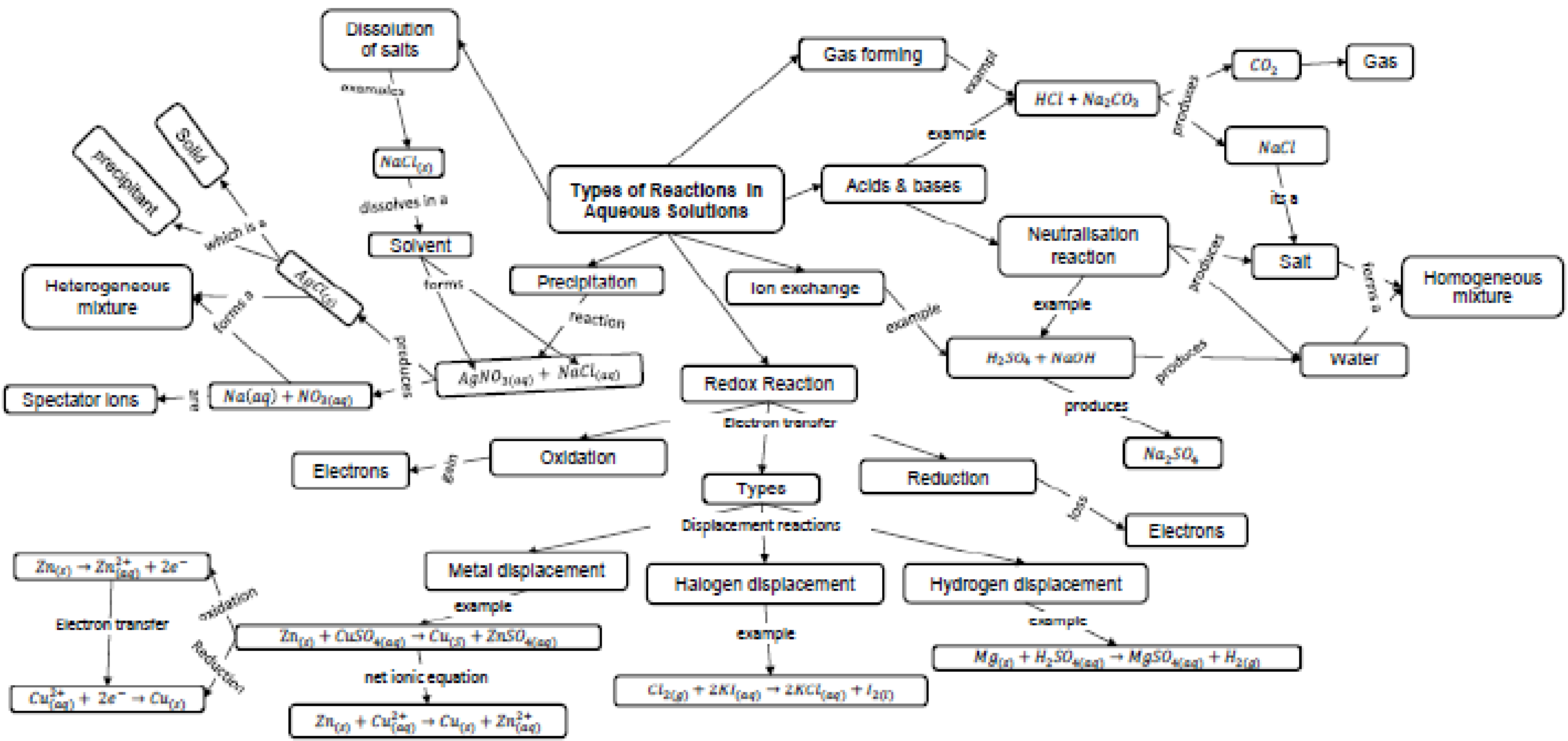


Figure 3.1 (a): The development of a concept map by myself

(b) KB 2 Analysis Version 3 teacher

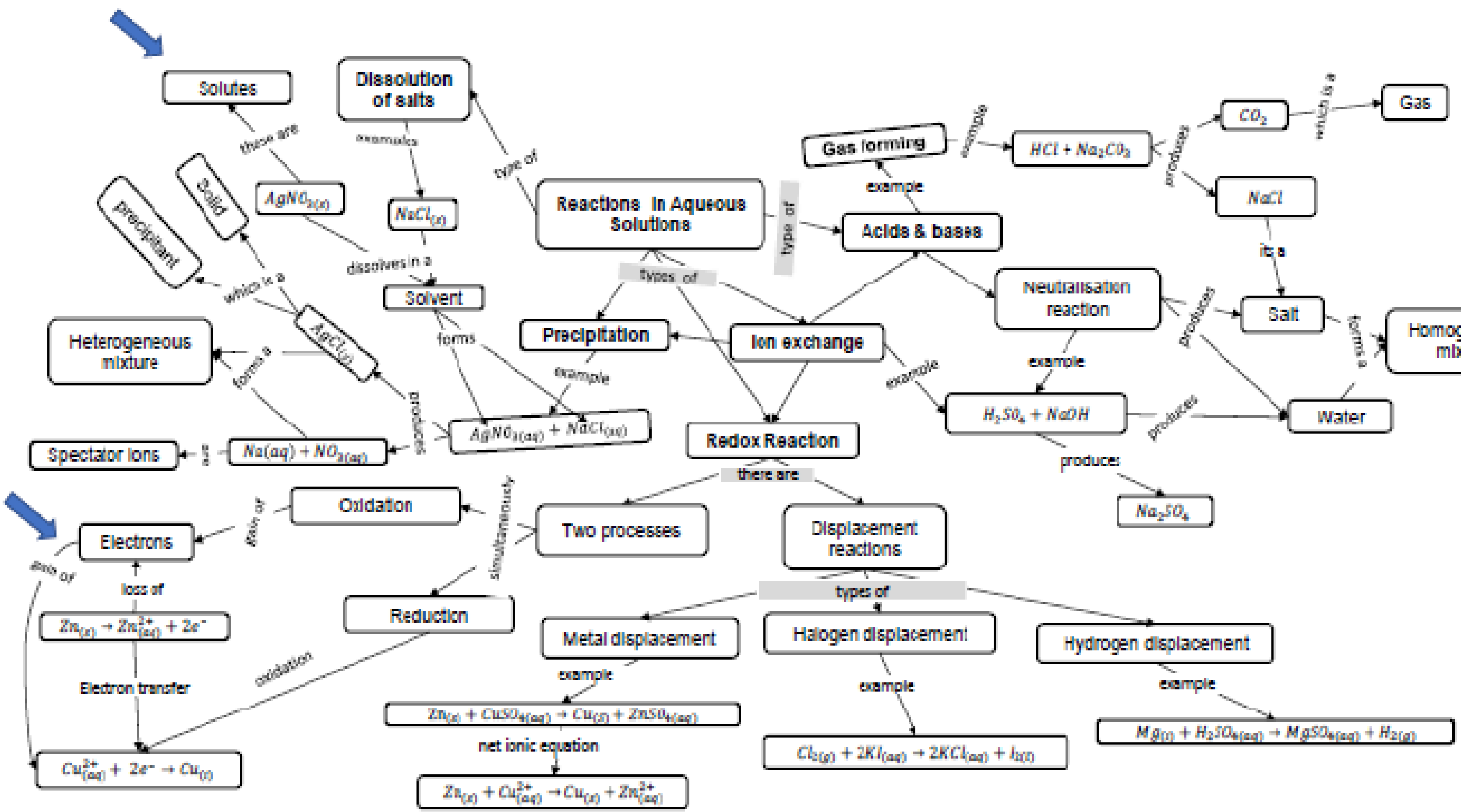


Figure 3.2 (b): The development of a concept map through member checking (Teacher)

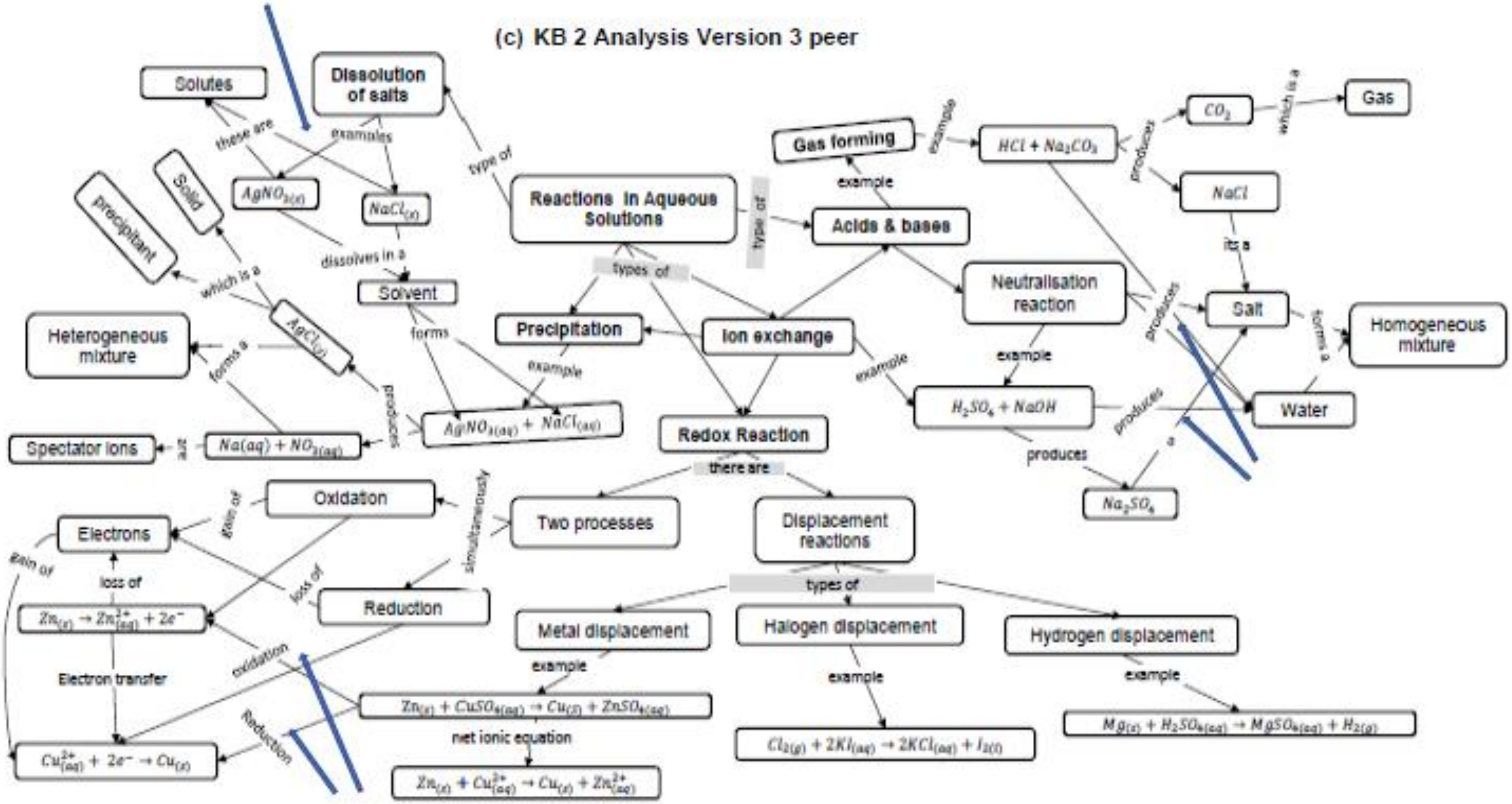


Figure 3.3 (c): The development of a concept map by a peer

Peer briefing is another process used by researchers to improve the credibility of qualitative inquiry (Amankwaa, 2016). Krefting (1991) argues that peer debriefing or peer examination have the same principles as member checking, but the former involves the participation of impartial peers or colleagues who are knowledgeable in the qualitative inquiry approach. I had two colleagues who acted as peer examiners throughout my analysis process, and these were fellow doctoral students. The colleagues were given the memory stick with the same contents as given to the participants for member checking. However, I had already uploaded the participants' contributions in all the memory sticks given to the peer reviewers. Each peer reviewer was given a set of recordings (audio and video), transcriptions, and analysed results containing three grades from different teachers. The reviewer had to choose any two of the three grades given, and from those two the reviewer had to thoroughly go through one grade and give a general comment on the other grade. The contribution of one of the reviewers is indicated under KB 2 analysis version 3 diagram where the reviewer added links or connections, which are shown with the bold arrows. That KB analysis version three diagram became the final concept map to be discussed in the analysis chapters.

I was also in a group of doctoral and master students, who shared the same research supervisor, and the group acted as my critical friends. The group members met weekly in a semester where we presented our work; robust discussions followed the presentations. The discussions were quite valuable as they shaped ones' thinking around paradigms, methodologies and analysis of data. The work of my findings was also presented to the doctoral student weekend meetings organised by the university where every doctoral student was required to present in at least one of the four such meetings in a year. Furthermore, my work was presented to the Annual Conference of the Southern African Association for Research in Mathematics, Science and Technology Education (SAARMSTE) as well as the SAARMSTE research school which are annual events.

Another factor that enhances qualitative research credibility which was used in this study was triangulation. Triangulation is the evaluation of information collected from a diversity of data sources to cross-check data and interpretations (Fusch & Ness, 2015; Guba, 1981). Sargeant (2012) denotes data triangulation as to the use of various data sources to produce a more inclusive view of the study. In this study, three data sources were considered which were, mining of information on the sequencing of concepts, linking of ideas between and across grades from the documentation, lesson observations and teacher interviews. Each research question was addressed by at least two of the mentioned data sources.

Dependability is another criterion used to ensure trus2rthiness of qualitative research. According to (Cope, 2014), it refers to the constancy of the facts of findings over comparable settings. On the same note, (Seale, 1999) agree that the term dependability is consistent with reliability in qualitative research. A study would be classified as dependable if its findings were replicated with similar participants in analogous situations (Cope, 2014). However, the results of the qualitative research are barely replicable because the participants are human beings who are dynamic and versatile in their thinking. Nevertheless, the dependability of data was achieved when the steps of the research were verified through the examination of how information was gathered and analysis was done by peers and renown academics during doctoral weekend meetings and conferences. Audit trail of interviews and lesson observation transcripts, as well as notes on documents analysed, were made to ensure that data is consistent with the three tools.

The naturalists believe that findings of the qualitative study are rarely transferable but only relevant to their context (Guba, 1981). Stake (1978) argues that case study research is not chosen to produce a generalisation of results but to validate adaptation of generalisations. However, transferability may apply when two different contexts contain similar results.

Starman (2013, p. 39) also argues that generalisability of case study research is conceivable when objects and issues with resemblance are by identified in different settings. Guba (1979) claims that the higher the degree of similarity between two contexts the more transferable is the findings. In this study, the transferability of results was depended upon the degree of similarity of results between participating teachers in their different context. I collected and synthesised full descriptive data through interviews, audio and video recordings. From the full data description, comparisons were made to ensure judgement of similarity of results between contexts is not compromised.

In ensuring confirmability, I worked with fairness as much as possible and display the specific findings as found during the collection of data to peers, participants and more knowledgeable other academics in research conferences. Shenton (2004) posits that the researcher should work meticulously to ensure that the research's findings mirror the participants' ideas and experience instead of his view or bias. I demonstrated confirmability of the results through a thorough description of how conclusions and interpretations were arrived at and exemplifying that the findings were derived directly from the data (Cope, 2014). I further demonstrated the confirmability of the results, by providing rich quotes from the participants that depict each emerging theme.

3.8 Limitations of the Study

The results of this work may not be generalised because they are unique to the three districts in Gauteng province and to individual teachers who participated in the study and unique to the context where the teachers are working. Since the case study is of a single, unit or group and naturally, single members poorly denote whole populations; the case study is perceived to be an inadequate basis for generalisation (Stake, 1978). However, the information and evidence that was gathered will be able to inform teachers and academics about procedures that should be taken to ensure conceptual understanding of teaching and learning of science concepts in a topic Chemical Change.

The data gathered from the multicase study of five participating teachers was massive and needed much time for transcription and analysis. This limitation was overcome through the systematic organisation of data. My research was time bound and so does not allow for longer-term effects of the intervention to be observed. It was on a voluntary basis. However, there was no attrition of participants as all five participating teachers did not withdraw from the study.

3.9 Conclusion

A multicase study methodology with five voluntary purposefully sampled participants was pursued. Guided by an ontological assumption that the more teachers are involved, the more I come closer to the truth which is out there. The truth that had to be revealed was about why learners have difficulties in answering the abstract questions in electrolytic cells and its central concepts. Using observational, interviews and mining of documents as methodological tools the participants were studied in their natural context with care being taken not to influence the participants in any way. A total of eight lessons that were video and audio recorded, five interviews that were audio recorded and two documents were analysed using the pedagogical link-making tool. Research practices that ensure credibility and trustworthy of findings such as member checking, peer review and triangulation were employed in the research. The critical ethical issues of qualitative research were all taken into consideration by approaching relevant authorities to get excess into the field, and all consent of all participants and their representatives were sought successfully.

The following chapters focus on the analysis of the three questions. The first research question is dealt with in chapter 4 where the spirality of the CAPS Physical Science content document is put under the critical lens of pedagogical link-making to promote continuity. Chapter 5 deals with the same factor of continuity but on the lessons that I observed on the five teachers. Chapter 6 and 7 looks into the third research question where participants' teaching practices are put under the test of the knowledge building approaches of the analytical tool.

CHAPTER 4

Spiral Curriculum

4.0 Introduction

In this chapter, I seek to answer the question: to what extent do the Physical Science CAPS documents support the progression and coherence of Chemical Change concepts at FET level?

This research question focuses on the development of a scientific story within and across grades. The teaching and learning of scientific conceptual knowledge involve the identification of how scientific concepts themselves fit together in an inter-linked system. The South African Physical Science content document advocates a Spiral approach in Science, where learners construct an understanding of the concepts gradually over a period (Department of Education, 2006). This suggests that an idea is introduced in lower grades and is slowly built upon in successive higher grades.

The science concepts are linked from one grade to the other as well as from one topic to the other, which the Department of Education refers to as conceptual progression and conceptual coherence, respectively (Department of Education, 2006, 2011). Conceptual progression and coherence are equivalent to the pedagogical link-making to promote continuity that involves making connections between teaching and learning events separated in time (Scott et al., 2011). Therefore, pedagogical link-making to promote continuity and the phases of the spiral curriculum by Hadden (1999) referred to in Chapter 2, forms the analytical framework of this chapter.

In South Africa, an analysis of learner response to questions in the matric Physical Science paper indicates that Chemical Change is a difficult topic for high school learners. For example, the (Department of Education, 2014a) diagnostic report for the 2013 matric paper, showed that Chemical Change had the lowest percentage average among the three learning areas with 40.6%, compared to 57.7% of Matter and Material and 58% of Chemical Systems. Devetak et al. (2009) discovered that learners' understanding of Solution Chemistry under Chemical Change was weak and further argued that learners have reduced ability to use their knowledge of Chemistry in new situations.

4.1 Document analysis

Document analysis is a systematic method that is used to evaluate or analyse text (printed or electronic), artefacts or visual material (Bowen, 2009). In this research, the work schedule and Physical Science content documents are examined and interpreted using the PLM analytical framework. Furthermore, the two examined documents revealed some important insights (Merriam, 1998) on how the spiral nature of the topic electrolytic cell can be fully realised. My task was to ascertain the extent the current Physical Science curriculum is progressional or spiral. In addressing the research question raised above the Physical Science CAPS content document, and work schedules from Grade 10 – 12 were analysed to ascertain the progressional nature of the syllabus. The analysis was done across grades and within each grade.

4.1.1 Concepts progression across grades

The extract from the content document below shows an overview of topics under Chemical change.

Chemical Change	Grade 10	**Physical and chemical change** (separation by physical means; separation by chemical means; conservation of atoms and mass; law of constant composition).**Representing chemical change** (balanced chemical equations). **Reactions in aqueous solution** (ions in aqueous solutions; ion interaction; electrolytes; conductivity; precipitation; chemical reaction types) **Stoichiometry (**mole concept**). 20 hours**
	Grade 11	**Stoichiometry** (molar volume of gases; concentration; limiting reagents; volume relationships in gaseous reactions) **Energy and chemical change** (energy changes related to bond energy; exothermic and endothermic reactions; activation energy). **Types of reactions** (acid-base; redox reactions; oxidation numbers **28 hours**
	Grade 12	**Reaction rate** (factors affecting rate; measuring rate; mechanism of reaction and of catalysis). **Chemical equilibrium** (factors affecting equilibrium; equilibrium constant; application of equilibrium principles). **Acids and bases** (reactions; titrations, pH, salt hydrolysis). **Electrochemical reactions** (electrolytic and galvanic cells; relation of current and potential to rate and equilibrium; standard electrode potentials; oxidation and reduction half reaction and cell reactions; oxidation numbers; application of redox reactions). **28 hours**

Figure 4.1: An Overview of Chemical Change Concepts

The concepts described in Figure 1 under Reactions in aqueous solution are ions in aqueous solution, ion interaction, electrolytes, conductivity, precipitation chemical reactions types which are taught at Grade 10. In Grade 11, higher level topics include types of reactions such as acid-base reactions, redox reactions and oxidation numbers. Later, in Grade 12, students are expected to master acids and bases in more detail as electrochemical reactions[1].

These topics from Grade 10 to 12 show the progression of both content coverage and abstractedness. At Grade10, teachers are expected to teach two types of reaction ion exchange (precipitation, gas forming, and acid-base reactions) and redox reactions. According to the Department of Education (2011, p. 49) under redox reactions, students are expected to be taught

> *redox reactions which are an electron transfer reaction. (Use the charge of the atom as an indication of electron transfer, no redox reaction terminology is required here). Use the charge of the atom to demonstrate how losing or gaining electrons affect the overall charge of an atom.*

[1] This study is not focused on acids and bases but electrochemical reactions at Grade12 particularly electrolytic cell, where oxidation and reduction reaction half reaction, cell reactions, oxidation numbers, and application of redox reactions are covered

On the same page in the content document under guidelines for teachers the DBE outlines the reasons why the types of reactions are being studied in this grade. The DBE contend that it is to enable learners to balance equations; hence the emphasis is on charges and not on oxidation numbers.

The basic concepts of oxidation numbers if introduced earlier in this grade could prepare learners for higher concepts of redox reactions covered in Grade 11. In fact, the Department of Education (2011, p. 49) acknowledges the importance of oxidation numbers when it differentiates between redox reactions and ion exchange reactions using oxidations numbers and not the charge of an atom as stipulated above.

> *Displacement reactions in ion-exchange reactions and displacement in redox reactions differ due to no change in oxidation numbers of elements (in ion-exchange reactions) and change in oxidation numbers of elements (in displacement reactions in redox reactions).*

The learners and teachers are expected to use the scientific term (Redox reactions), but there is no emphasis from the CAPS documents to define its meaning. Although the curriculum developers correctly differentiate between displacement reactions and redox reactions using oxidation numbers, teachers are not teaching oxidation numbers in Grade 10. This because teachers follow an annual teaching plan that is distributed by the DBE to all schools. The yearly teaching plan has dates and time frames that should be strictly adhered to. Hence, teachers follow it precisely as their content coverage is measured using the annual teaching plan.

Consequently, the concept of oxidation numbers is not covered by the teachers despite that it's recommended in the CAPS Physical Science content document. Therefore, at Grade 10 learners are expected to be taught the balancing of equations using charges. However, oxidation numbers are a necessary aspect of how the different species have attained the charges due to electron loss or gain.

Allowing learners to use technical terms without understanding their meaning promotes learning by memorisation. The aspect of linking oxidation numbers with charges would augment both the understanding of balancing of chemical equations and redox reactions. For the curriculum developers to negate the use of oxidation numbers at this stage further complicates the balancing of equations at the Grade 10 level. The oxidation numbers should be introduced at Grade 10 level, especially the rules and calculation of simple molecules. Once they are equipped with the understanding of oxidation numbers learners will easily comprehend the balancing of educations. Jensen (2009) argues that the purpose of charges and inspection in balancing equation is a haphazard approach that is insufficient in balancing redox reactions. The CAPS Physical Science content document requires the exploration of broad concepts at this level. However, the omission of one essential idea will present a challenge to teachers as it creates a gap in the development of a full scientific story for redox reactions.

The terminology and concepts of redox reactions and oxidation numbers should be introduced at Grade 10 level and links made to learner prior knowledge in upcoming grades. The Grade 12 concepts, like electrolytic cells and their applications, mark the completion of the reactions in aqueous solution – a conversation that started in Grade 10 already. Figure 4.2 below indicates how the topics are sequentially organised across the grades.

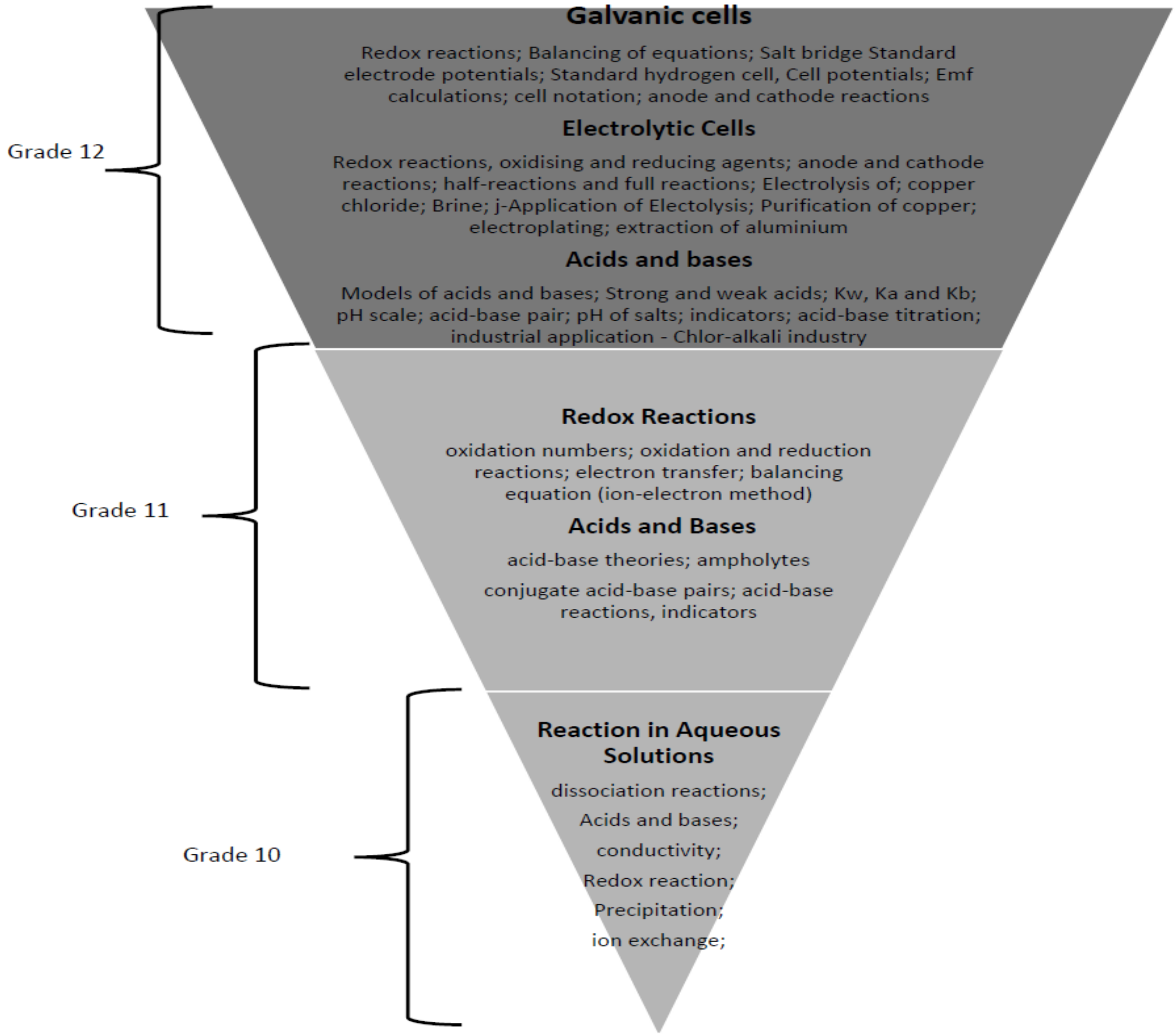


Figure 4.2: Progression of concepts across grades

Figure 4.2 above shows that the content structure of Chemical Change in the Physical Science Content document is Spiral in nature. Few and simple concepts of solution chemistry are introduced at Grade 10. These basic concepts form a foundation of more complex concepts in higher grades. The complexity and broadness of concepts increase in higher grades. For example, the concept of acids and bases in Grade 10 deals with simple definitions and classification of acids and bases as well as simple neutralisation reactions. The concepts are developed further at Grade 11 where more concepts such as theories of acids and bases, more and complex acid-base reactions are presented. At Grade 12 more concepts that are linked with Grade 11 concepts are introduced.

However, the Grade 12 concepts are many and more complex than those in Grade 10 and 11 as shown in Figure 4.2 above.

The acids and bases example is different from that of electrolytic cells. In that, some of the basic pre-requisite concepts are missing at the foundation level (Grade 10), and there are other concepts also missing at Grade 11. For example, at Grade 10 the concept of oxidation numbers is missing, it is not included in the annual teaching plan. At Grade 11 the concept of electrolytes which should be linked to the conductivity of solutions at Grade 10 is not included in the teachers' annual teaching plan.

Besides the omission of oxidation numbers in Grade 10 as mentioned above, other essential concepts omitted are electrolytes or simple electrolysis in Grade 11. Students are not exposed to any idea that refers to electrolysis during the whole year of chemistry in Grade 11. That creates a gap in the development of the concepts. Learners then have to only rely on their understanding of conductivity and electrolytes covered in Grade 10 when they explore the idea of electrolytic cells in Grade 12. Thus, concept gaps within a spiral curriculum impede conceptual progression and hamper meaningful learning.

The concept of conductivity and electrolytes is developed in Grade 11. In this Grade, learners are introduced to an investigation of good and weak electrolytes by decomposing conducting substances using electricity. This concept does build on the knowledge of non-conducting solutions (non-electrolytes) and conducting solutions (electrolytes) covered in Grade 10, thereby closing the conceptual gap. In this section, I discuss how the CAPS curriculum addresses the progression between grades, separated by years (macro scale) and I highlight the weakness and strength of the syllabus regarding the hierarchical arrangements of topics. The next section analyses the cohesion of concepts between topics within the grade addressing the macro scale (separated by months and weeks) and the meso scale (separated by days and lessons) links that are designed to promote continuity.

4.1.2 Arrangements of topics across grades

The topics in the two documents, the CAPS content document, and the work schedule are arranged according to the four school terms of the year. The content document outlines the topics that should be covered per term and the work schedule details time frames of the term, month, week and the number of hours that should be spent in teaching a topic or concept. Teachers are supposed to follow the time frame to the letter, and there is a monitoring tool called the Curriculum Management Model (CMM) in place to check the syllabus coverage for each teacher. There is no leeway to change the way the topics are ordered in the work schedule. See Table 4.1 below.

Table 4.1: Sequence of the topic in the work schedules from Grade 10 to 12

Grade	Term	Work Schedule Topic Sequence
10	Term 1	States of Matter & The Kinetic Molecular Theory – Atomic Structure – Chemical Bonding – Waves – HOLIDAY.
	Term 2	Atoms, Compounds & Molecule – Chemical Change (Matter & Energy - Balancing Equations) – Magnetism – Electrostatics – Electric Circuits – HOLIDAY.
	Term 3	Chemical Change (Reactions in Aqueous Solutions) – Mole Concept – Mechanics – Hydrosphere – HOLIDAY.
11	Term 1	Vectors – Newtonian Physics – Chemical Bonding – Intermolecular Forces – Chemistry of Water – HOLIDAY.
	Term 2	Geometrical Optics – Waves – Ideal Gases – Quantitative Aspects of Chemical Change – HOLIDAY.
	Term 3	Electrostatics – Electromagnetism – Electric Circuits – Power & Energy – Energy and Chemical Change – Types of Reaction (Acids & Bases, Oxidation Number, Redox Reactions) – Mining
12	Term 1	Practical Skills – Momentum & Impulse – Vertical Projectile –Organic Chemistry – Work, Energy & Power – Doppler Effect – HOLIDAY.
	Term 2	Rates of Reaction – Chemical Equilibrium – Acids & Bases – HOLIDAY.
	Term 3	Electric Circuits – Electrodynamics - Alternating Current – Optical Phenomena – Electrochemical Reactions – Chemical Industry – HOLIDAY.

Generally, each Physics topic is covered in whole without being separated by a Chemistry topic or a holiday for that matter, in all the grades. However, the evaluation of their coherence is beyond the scope of this study. Why Physics is easier to arrange than

Chemistry is that each topic is distinct with a little significant relationship between waves and the electric circuit at this level, for example. In contrast, chemistry topics are interrelated, and one needs to be careful where an unrelated physics topic must be fitted between chemistry topics. Consider the sequence of topics in Grade 10 first term and second term as extracted from Table 4.1:

> Atomic Structure – **Chemical Bonding** – Waves – HOLIDAY – **Atoms, Compounds & Molecule** – **Chemical Change (Matter and Energy & Balancing Equations)** – Magnetism – Electrostatics – Electric Circuits – HOLIDAY – **Chemical Change (Reactions in Aqueous Solutions)** – Mole Concept.

Chemical bonding and atoms, compounds and molecules are related topics with interlinking concepts. However, these topics are separated by the concept of waves. There is also a three week holiday in between the first term and second term. It means that when resuming the topic of atoms, compounds and molecule in the second term teachers and learners cannot refer to any meso scale concepts that are separated by weeks and days.

The topic of chemical change is divided into two portions by Magnetism, Electrostatics, and Electricity, which lasts for three weeks followed by a 2-week holiday. Reactions in aqueous solutions hardly show interlinking of meso scale because the previous topic is of Physics, which is unrelated to the chemistry concept. This trend is the same for both Grade 11 and Grade 12 work schedules (see Grade 11 topic sequence below)

> Vectors – Newtonian Physics – **Chemical Bonding** – Intermolecular Forces – Chemistry of Water – HOLIDAY. Geometrical Optics – Waves – Ideal Gases – **Quantitative Aspects of Chemical Change** – HOLIDAY. Electrostatics – Electromagnetism – Electric Circuits – Power & Energy – **Energy and Chemical Change** – Types of Reaction (Acids & Bases, Oxidation Number, Redox Reactions) – Mining

In Grade 11, the topic chemical change is again split into two parts by the same topic of electrostatics, electricity, magnetism and power and energy with a duration of five weeks and a 3-week holiday. However, the concept of redox reactions which is the focus of this study is in the third term. The topic is covered after the physics topic of electric current and magnetism. That is, there are no meso scale link-making opportunities for teachers and learners in Grade 11 at the beginning of the Redox reaction lessons. On the contrary, Grade 12 sequencing of concepts is as bad as that in Grade 10. The Electrochemical cell concept is covered after electromagnetism and electricity. It is separating Electrochemical cells from rates of reactions and acids and bases by a gap of six weeks including a three week holiday. Hence, the meso scale will not be realised in the teaching of electrochemical cell especially the first lesson.

> Practical Skills – Momentum & Impulse – Vertical Projectile –Organic Chemistry – Work, Energy & Power – Doppler Effect – HOLIDAY. **Rates of Reaction – Chemical Equilibrium – Acids & Bases** – HOLIDAY. Electric Circuits – Electrodynamics - Alternating Current – Optical Phenomena **– Electrochemical Reactions –** Chemical Industry **–** HOLIDAY.

These gaps do not encourage coherence and flow of ideas from one concept to another. Learners get disjointed pockets of concepts which are not clearly linked thereby encouraging rote learning. These gaps and irregular work schedules have a significant impact on teaching and learning considering that teachers are expected to implement them as they are.

4.2 Linking to the Lesson observation

The pedagogical link-making to promote continuity is about showing inter-linking of concepts during teaching and learning events. Pedagogical practices of interlinking concepts to show continuity must be an essential part of the scientific story with accumulative links being explicitly taught to learners by the teacher (Mortimer & Scott, 2003). It is the teacher's responsibility to point out to learners the connections between current concepts and previous or future discussed/learned concepts. Learners must be afforded ample opportunity to talk through what they know about an idea, which becomes a base for a new concept to be taught (Mercer & Dawes, 2008).

The teacher should develop and maintain dialogues that involve learners' understanding of previous concepts. Scott et al. (2011) identify two approaches that teachers can employ to enrich the discourse; to develop the scientific story and to manage or organise learning activities. The first approach has three significant time frames that the teacher must refer to during lesson delivery. Reference should be made to events or concepts that took place in the previous months, term, or year (macro scale) in various chunks of the science curriculum. To continue developing the full scientific story the lesson conversation can be extended to immediate past lessons covered over weeks or days (meso scale).

Furthermore, a reference to the dialogue can be separated by minutes, usually of short time intervals (micro-scale). That is within the lesson; the teacher or the learners can refer to concepts discussed earlier in the lesson. The main issue is to develop a coherent and well-structured scientific story. The teacher must identify and point out the links that enable learners to share their understanding of the concept.

4.3 Conclusion

This chapter presented an analysis of the CAPS Physical Science content document and the annual teaching plan (work schedule) on the topic of electrolytic cells and its underlying concepts. There are three outstanding outcomes. Firstly, the topic Reactions in aqueous solution, Redox reactions and Electrolytic cells exhibit the general characteristics of a spiral curriculum. However, some crucial topics are missing in both Grades 10 and 11, for example, oxidation numbers (Grade 10) and Electrolytes (Grade 11). Secondly, the concept of oxidation numbers is mentioned in the CAPS Physical Science content document for Grade 10 but does not appear in the annual teaching plan. The concept is not taught in Grade 10, resulting in an overloaded Grade 11 content where the full topic of oxidation numbers is taught.

The concept of oxidation numbers should start and be taught at Grade 10 to create a base upon which further ideas will be built upon. Thirdly, the electrolyte concept is superficially introduced in Grade 10 and omitted in Grade 11 and then covered more comprehensively in Grade 12. Such an arrangement and sequencing of topics creates a conceptual gap in Grade 11 and creates an overload of concepts in Grade 12

Hence, the curriculum does comply with the vision of spiral coverage of concepts at the FET level (Grade 10-12) regarding the arrangement of topics. However, the spirality is compromised by the actual arrangement of themes and concepts across grades and teaching for understanding is undermined. In the next chapters, the feasibility of the successful implementation of such a curriculum is put to the test through an analysis of actual lessons observed and teacher interviews. These were subjected to the continuity and knowledge building analytical tool to determine the extent to which teaching creates opportunities for link making and conceptual cohesion.

CHAPTER 5

Pedagogical link-making to promote continuity

5.0 Introduction

Chapter 5 focuses on addressing research question two: to what extent do the practices of teachers promote continuity in the teaching of Chemical Change at Further Educational Training phase?

Link-making to promote continuity is the second form of pedagogical link-making that involves making connections between concepts that have been taught over different time scales (Scott et al., 2011). The science curriculum or any other curriculum is covered over a period, and for the South African FET phase, it is over three years (Grades 10 to 12). During teaching and learning activities concepts must be linked to other related concepts that have been covered in the past or to be covered in future. The teacher must maintain the scientific story of a concept by making links between interrelated concepts.

As teachers keep track of concepts' inter-relatedness over various times, emphasis must be placed on conceptual coherence. It is not only the teacher's responsibility to make links between concepts, but the teacher should purposefully and explicitly show the connections and provide opportunities to help learners work on them on a social plane. Scott et al. (2011) identified two approaches to promote continuity, and these are to develop the scientific story and to manage or organise time. However, this research is concerned with the development of a scientific story.

5.1 To develop the scientific story

The focus of pedagogical link-making to promote continuity is to develop a scientific story from learners' substantive content of the lesson through classroom participation. Mortimer and Scott (2003, p. 19) define the progression of the scientific story as "providing a commentary on the unfolding scientific story, to help learners follow its development and to see how it fits into the wider Science curriculum." The development of a scientific story is depended on the ability of the teacher to link concepts in current lessons with subsequent lessons using learners' previous knowledge. Scott *et al.* (2011) argue that links can be made during the lesson through recaps and elicitations.

As mentioned earlier, the link to develop scientific story approach has three categories, namely, macro, meso and micro (Scott *et* al., 2011). The first lessons of all five teachers were analysed to ascertain how the lesson was introduced and what links were made in the build-up of the concept that was taught. The concluding lesson was also analysed to determine how teachers sum up the lessons using links to tell the scientific story of the entire topic. Each grade was analysed separately, and comparisons were made between teachers per grade and across grades.

5.2 First lesson general analysis on link-making

The lessons of the five teachers I observed were transcribed and analysed using the Scott et al. (2011) framework and Table 5-1 below shows the number of link-making done by each teacher and the concepts which were linked during the lesson.

Table 5.1: Links made in the first lesson by each teacher

Grade	Teacher	Total time	Links	No. of Links	Concepts linked in the lesson
10	Zulu	22	PC1-1	2	Formation of a precipitate, Formation of a solid
			PC1-2	2	Electrolytes, Types of Chemical Reactions
			PC1-3	1	Chemical Bonding
	Johannes	30	PC1-1	8	Ions in solution x 2, dissociation of salts x 3, Representational diagrams of NaCl solution x 3.
			PC1-2	3	Types of Chemical Reactions, Ion exchange, Dissolution of Salts
			PC1-3	3	Chemical Bonding, water cycle, Mixtures
11	Ndebele	58	PC1-1	13	Rules of oxidation numbers x5, Polyatomic molecules x 3, Video Clip x 2, Calculations x 2
			PC1-2	1	Acids and bases
			PC1-3	4	Ionic Bonding, Periodic table x 2 Monoatomic Elements.
	Meyer	62	PC1-1	18	Electron Transfer X 4, Rusting of Iron X 3, Electronegativity X 2, Periodic Table, Electron Transfer X 4, Rusting of Iron X 3, Electronegativity X 2, Periodic Table, Transition Metals, Calculations Done by Learners X 2
			PC1-2	3	Redox Reactions, Rules of Oxidation Numbers
			PC1-3	19	Ionic Bonding X 2, Periodic Table X 3 Electrostatic, Electronegativity, Transition Elements X 2, Electric Current X 2, Chemical Reactions, Electronic Structure, Aufbau Diagrams, Energy Level,
12		40	PC1-1	7	Electron transfer, Redox reactions, reduction, oxidising agent, reducing agent, anode, and cathode
			PC1-2	0	
			PC1-3	9	Redox reactions, reduction, oxidising agent, reducing agent, anode, and cathode, half-reactions, spectator ions, balancing of equations.
	Masutha	12	PC1-1	4	Anode, cathode, electric current, decomposition
			PC1-2	0	
			PC1-3	5	Electrolytes, conduction of electricity, dissociation, Electrodes, Decomposition of electrolytes

Table 5.1 above shows that most links were made by Grade 11 teachers followed by Grade 12 teachers and Grade 10 teachers had the least number of connections made in the first lessons. The table shows the concepts which were linked in each grade by each teacher per topic. How the various ideas were related to each other would be analysed and discussed later in this chapter. A vivid picture of these differences is depicted in Figure 5.1 below.

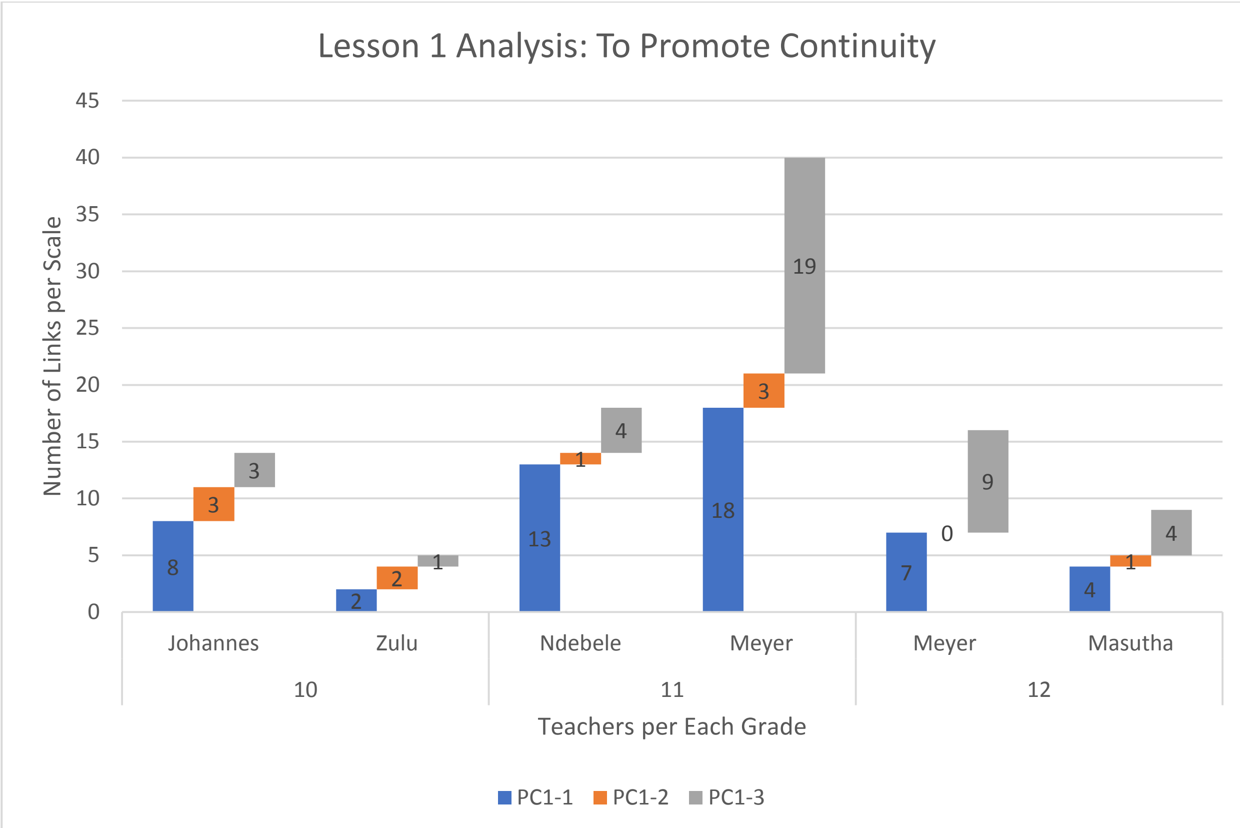


Figure 5.1: Number of links per teacher for the first lesson

The graph in Figure 5.1 above shows that Mrs Meyer had the most link-makings made in the lesson that lasted for 62 minutes with the Grade 11 class followed by Mrs Ndebele who had had a total of 18 links in a lesson that lasted for 58 minutes. Zulu had the least number of links (5) with a Grade10 class, a lesson that lasted 22 minutes. Mr Masutha's first lesson was the shortest observed (15 minutes), and he managed to make ten links with a class of Grade 12 learners.

There is a striking general trend from the graph above; teachers had a lower score on macro scale than any other link-making except for Mrs Meyer and Mr Masutha. This observation is expected in Grade 10 classes as learners are starting a new subject in a new phase, and macro link-making with the previous phase might be limited due to the different scopes of the two phases in content material. As from Grade11 and 12, the story is different as each topic is linked to the previous grade hence a high linking score from

Mrs Meyer who knew what was expected in link-making due to her previous encounter with the approach. Grade 11 and 12 were expected to have a sizeable number in both macro, and meso scales as the curriculum is progressional and spiral.

There are two significant reasons why the macro scale of linking was not realised in these introductory lessons which are supposed to be anchoring the previous knowledge with new coming content that was to ensure meaningful learning. The first reason is that there are two topics to be covered in Grade 11, namely, Redox Reactions and Oxidation Numbers. Redox reactions were done in Grade 10, but the scope was limited to precipitation reactions, and the terminology such as reduction and oxidation were not recommended to be taught at Grade 10.

As for the topic of oxidation numbers as alluded to above the work schedule which is the teachers' working document is silent about the oxidation numbers in Grade 10, and during the teacher interviews, teachers had an understanding that it should only be done in Grade 11. Although the curriculum statement on teachers' guidance column encourages teachers to differentiate between ion exchange and redox reactions using the oxidation numbers, the teachers confessed that they never taught the concept. The fact that it was not stated in the content, concepts and skills column in the work schedule shows that it was omitted even by a national subject specialist who designed the work schedules for teachers. That gap compromises the linking of the concept from one level to another and will not ensure the coherence of topics and the spiral nature of the curriculum at the implementation stage.

In addition, the teachers mentioned that the syllabus was fully loaded, and there was no time to engage learners with the previous year's work as they will be racing to keep up with the work schedule. The issue of time was discussed during the first debriefing meeting on the thrust of the project I did with them, and we were discussing the reason why the electrolytic cell questions are poorly done in the final examination, the excerpt below attest to that.

40	*Researcher*	*...What is learners’ performance on the topic electrolytic cell in the final examinations*
41	*Meyer*	*It is always bad*
42	*Researcher*	*What is the contributing factor and what are the underlying concepts of the electrolytic cell that should be taught thoroughly at the lower levels*
43	*Ndebele*	*I just wanted to say… just to add on to what ma’am was saying. That questions were more conceptual …. Now we asked for them to… answer the conceptual questions. It is even more challenging to some of them. That was another contributing factor which I think made the pass rate to go down.*
44	*Researcher*	*Okay... What are the underlying concepts ...*
45	*Masutha*	*Redox, they need to understand the redox reactions*
46	*Researcher*	*Redox reactions…?*
47	*Masutha*	*Yes, redox reactions in grade 11*
48	*Zulu*	*I wanted to say it does start from Grade 10*
49	*Researcher*	*Ya… ok …*
50	*Zulu*	*The concepts start in Grade 10. If we could, if the learners grasp the concept at Grade 10, I do not think that we should have a problem going forward. I mean if we are, to be honest, some of these things we are doing it in a rush (participants in agreement), because of the time factor is not it so? We are doing it in a rush we just want them just to squeeze and blah blah then we move and go on to Grade 11. We think that is our thinking now that we should have grasped these things in Grade 10, and then we move on. However, if we polish it in Grade 10, I do not think that we will be having this problem. ….*

Most of the participating teachers agreed with Mr Zulu that they do not get enough time and they are always rushing through the syllabus. In my first observation of Mr Zulu’s teaching, I noticed that his first lesson which was supposed to be 40 minutes was 22 minutes long. Because on that day there was a whole school assembly in the morning, and it was longer than the time slot it had on the school timetable. After the assembly learners took their time to get into the class. The fact that learners trickle late into the class was observed in all the classes in the five schools although this was worse in township schools. Hence, lessons were never observed in the actual time they were supposed to be taught as per timetable. However, this was not the only reason why teachers rushed through the syllabus; excerpt below captured another critical reason why there is a rush in syllabus coverage.

74	*Researcher*	*How can we teach the curriculum without being in a rush what is the problem why are we rushing?*
75	*Ndebele*	*Okay, when I… look at the scheduled fine, it has coverage, but I do not… I usually comment… my schedule does not cater for all my needs it is not fair to everyone, yes for the fast learners but for the least, slowest learners it does not cater for them even though I have morning lessons… Under normal circumstance, if there is positive contact time my learners should understand but now, I try to put extra lesson whether morning or afternoon but still my least learners they are not catered for with my schedule… I think… I have always commented on there that it does not cater to all my learners, worse the slowest learners.*
76	*Researcher*	*So, you will need more time, especially with the challenged learners, right?*
		……………...
86	*Johannes*	*Okay, I also wanted to say something concerning what she said about the work schedule not catering for her least learners. I have always noted that this work schedule… I think it is overloaded… if you do not do extra lessons using the normal time on the timetable, you do not finish it… just finishing it, I am not talking about revision. So, we need to make extra time to finish the syllabus number 1; we need to make extra time for revision. …….*
		So, I think the syllabus must cater number 1 for the revisions; space must be there for us to revise thoroughly with them.

Scrutinising the three schedules and the curriculum content document, they show that the planning has been done until to the last day of learning without considering any form of revision. The only exception is in the Grade 12 work schedule where ten hours of revision is allocated for both paper one and two topics that are for the entire syllabus. Teachers are doing extra classes and are utilising the contact time but all the same, they fail to finish the syllabus. It is difficult for the teachers to be patient with the slow learners as they need time which teachers do not have because they will be rushing to keep up with the work schedule. Hence, it is almost impossible to employ the teaching strategies that foster conceptual understanding as they require teacher and learner engagement through discussions. The discussions are supposed to link with what they know, and the coming knew knowledge. To save the time of completing the syllabus the teacher tells learners what he or she knows. To those teachers who are conscious about making links, they instead will make the connections themselves instead of learners making the links in a dialogic environment.

So, because of the 2-reason mentioned above, it was found out that macro scale links are very few as teachers are concerned with covering the lesson at hand negating conceptual link-making and consequently neglecting approaches that enhance meaning-making in the classroom. That is the reason why the macro scale scores are very low for the rest of the teachers. However, there is a need to scrutinise how each teacher made the links and how important were those links to fostering the approach of conceptual understanding of the scientific concepts.

5.2.1 Grade 10 First lesson analysis

Mr Zulu's first lesson was on the concept of precipitation in Reactions in Aqueous Solutions, a topic covered at Grade 10 under Chemical Change. His previous lesson was on electrolytes, and the teacher started his lesson by recapping on that concept, and the conversation is captured in an excerpt below.

Turn	*Speaker*	Transcription
1	*Zulu*	*Good Morning.*
		(Learners are still trickling into the classroom)
		Boys remove your hats and girls you can put them on.
		(The teacher settles the learners)
		Back to our work now last time we were talking about electrolytes is that correct?
2	*Class*	*Yes*
3	*Tr.*	*We said electrolytes were substances. (disturbances by latecomers)*
		We said they were substances which dissociate in water to form ions is that so? Moreover, I gave you homework of three of them that is, sodium chloride, potassium bromide, and potassium permanganate. Then I said to show the dissociation of this into their ions.
		Who did the homework? Can somebody to do it for us. How does it dissociate into its ions?

(Teacher moving around checking learner's work)

Right Sessi can you go and do it on the board what you did there.

(Learner goes on the board and works out the equation of dissociation quietly, she wrote the following equation)

$$NaCl_{(s)} \rightarrow Na^{+}_{(aq)} + Cl^{-}_{(aq)}$$

The teacher explains Sessi's work on the board

Right, first one- Sodium chloride.

When sodium dissociates in ions, it will form a sodium ion (+) positive one and chloride (-) ion negative. Correct

4	*Class*	*Yes*
5	*Tr.*	*Moreover, we did this when we were looking at bonding in term 1, where electrons are moved from the sodium atom to the chlorine atom.*

Now because of time, I am going to give you the memo for the other two is that so.

The story is the same which means here my potassium 1 + bromide negative and this one was going to give you a challenge ne because they are three atoms now. However, when you take the metal potassium, whatever remains and then it becomes negative correct.

In turn one, the teacher is pointing out that the class discussed electrolytes in the previous lesson (meso scale – PC1-2), which Sessi vividly remembered and she successfully summarised it in the form of an equation. The story of ions in aqueous solution is a foundation for the future concepts of precipitation where ions react to form a solid. The teacher successfully identified the link which the learner answered accurately, making sure the story unfolded without a problem.

The teacher further made a macro scale (PC1-3) link, where he referred to chemical bonding done in term 1, and this was term three (turn 5). It was going to be interesting if the teacher had allowed the conversation to continue had he engaged learners on the concept of chemical bonding. The conversation was going to show us how learners would have connected the lesson at hand with concepts discussed approximately six months ago. Here the teacher denied himself an opportunity to assess if this concept was well understood then. Chemical bonding is an underlying concept in the formation of a precipitate and learners should be able to refer to concept to show conceptual understanding of the topic of precipitation reactions.

Mr Zulu terminated the dialogue on chemical bonding and revision of homework altogether because of time, see the turn 5 when he said that *‘Now because of time, I am going to give you the memo for the other two is that so?”.* Other learners could not be evaluated on the concepts of electrolytes because of time. Time was the reason the teacher had to rush to cover the day’s topic, but he successfully linked two concepts, that are electrolytes and precipitation reactions. The link also marked a transition between the marking of homework and starting the discussion of the new topic.

If the discussion around chemical bonding was given ample time, I could have managed to how learners comprehended the scientific events discussed over an extended time (macro scale). That was going to provide full evidence, of whether learners conceptually understood the concepts then. An opportunity to evaluate how chemical bonding could have been linked with precipitation reactions in a manner that showed the cohesion of concept was lost because learners were not given adequate time to discuss. Table 5.3 below an extract from Table 5.2 shows Mr Zulu’s total number of links per category for the whole lesson.

Table 5.2: Mr Zulu’s links to promote continuity lesson 1

Continuity Links	**Code**	**No. of Links**	**Topics**
Micro scale	PC1-1	2	Formation of precipitate Formation of a solid
Meso scale	PC1-2	2	Electrolytes Types of Chemical Reactions
Macro scale	PC1-3	1	Chemical Bonding

Table 5.2 above demonstrates that the number of links was quite minimal for the entire lesson in Mr Zulu’s class. Hence, there were very few incidents where the teacher linked

the concept taught in a lesson with other topics across the Chemistry curricula or within the lesson. Figure 5-1 above shows the graphical representation of the different links that were made by Mr Zulu. For a forty-minute period, which was reduced to twenty-2 minutes due to a more extended assembly, Mr Zulu managed to make a total of five links. They were for linking the precipitation reactions with other concepts across the science curriculum. Table 5-1 above displays the topics that he referred to during his lesson delivery.

Mr Zulu made five links with four different concepts to develop the scientific story of precipitation reactions. The way the story was developed is depicted in Figure 5-2 below.

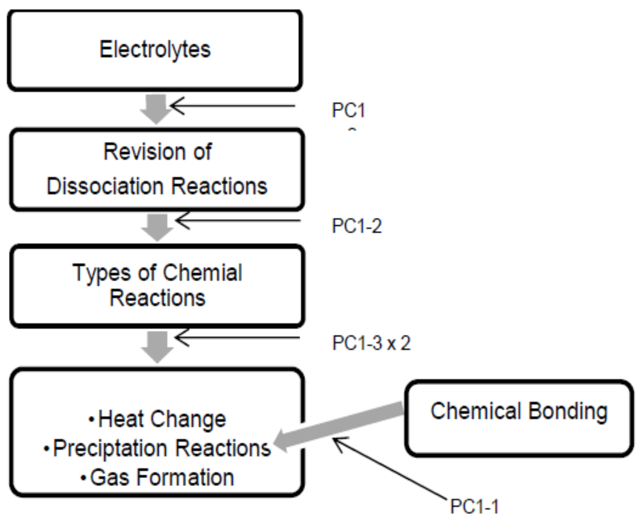


Figure 5.2: Mr Zulu's lesson one concept structure and links

The topics referred to in the class discussion were entirely relevant, but the question remains, did Mr Zulu exhaust all necessary concepts that would have enhanced learner understanding of other concepts? Now Let us consider Mr Johannes's lesson which I observed during a Grade 10 lesson, and then in this space comparisons can be made.

Mr Johannes was teaching the same lesson but at a different school. In accordance with the department of education's work schedule, the topics and concepts were to be taught at the same time by all teachers who follow a prescribed work schedule. The excerpt below shows how Mr Johannes introduced his lesson.

1	*Johannes*	*When I introduced this topic to you yesterday, I said when we look at Chemical Reactions, there are two types of chemical reactions; Ion Exchange and Redox Reactions is that so?*
2	*Class*	*Yes*
3	*Johannes*	*From there, looking at the redox reaction there are three types, we have got precipitation reaction, gas forming reaction and acid-base reactions. We start by looking at precipitation reaction, are we together?*
4	*Class*	*Yes*
5	*Johannes*	*Before I get into more detail, we also looked at the dissolution of salts, when we were adding salt into what?*
6	*Kenny*	*To water*
7	*Johannes*	*To water. When we added salt into the water, we found out that, what do they do?*
8	*Siya*	*They dissolved*
9	*Johannes*	*Some dissolved ne?*
10	*Class*	*Yes*
11	*Johannes*	*When they dissolved, they form what?*
12	*Kenny*	*They form a solution*
13	*Johannes*	*They form a solution, is that so?*
14	*Class*	*Yes*
15	*Johannes*	*That is correct. So today we are using solutions that are going to have those ions, are we together. What I am going to do right now I shall first give you worksheets, and from those worksheets, I am going to demonstrate an experiment in which we are going to have ions reacting in a precipitate reaction. Yesterday when I was giving you the type of reactions, I think I did define what precipitate reaction is? But let me just add on to that. From Geography, we know that there is precipitation when we look at the water cycle, are we together?*
16	*Class*	*Yes*
17	*Johannes*	*When you look at the water cycle, we have water falling as what?*
18	*Mattie*	*Solid*
19	*Getty*	*Snow*
20	*Johannes*	*They fall as what?*
21	*Class*	*Snow*
22	*Johannes*	*As snow ne*
23	*Class*	*Yes*

24 Johannes *Very correct besides snow, they can fall as what?*

25 Class *As rain*

26 Nolly *As hail*

27 Johannes *As hail, besides that it can fall as what?*

28 Sihle *As rain*

29 Johannes *As rain ne. So when we talk about precipitation is something that is coming from somewhere, now from the water cycle, it is water falling from the sky. But when we are looking from a chemical reaction, precipitation is the falling of a solid out of a solution. The falling of a solid out of what?*

30 Class *Solution*

31 Johannes *The solution, this occurs when you react to two solutions that a clear. Remember a solution is homogeneous….*

32 Class *Mixture*

33 Johannes *The mixture is that so? So, if it becomes a heterogeneous mixture, we are now having a solid. It means it is a precipitate kind of a reaction. So, I am first of all going to give you some worksheets and be in groups. Let us have, some groups of five please so 5, 5, and 5.*

(Teacher distributes worksheets to learners seating in groups).

In the extract above, the teacher links the previous lesson with the current topic, the meso scale link (PC1-2), turn 1. The concepts linked were Ion Exchange and Redox reactions. In turn 5, Mr Johannes makes meso scale (PC1-2) link again when he referred to the dissolution of salts, and the concept had to do with releasing of ions into solution. The teacher engages the whole class in a discussion and with individuals to access the understanding of the previous lesson.

The water cycle is a discipline link (macro scale – PC1-3) between Grade 9 Geography content and Chemical Change in Grade 10 and shows the conceptual progression from one grade to another. The link between precipitation reaction and heterogeneous mixtures is also a PC1-3 as Matter and Material was done in the first term. However, these were one-word answers which indicated a factual and not conceptual understanding of the concept. The diagrammatic conceptual outline is shown in Figure 5.3 below. The concept flow diagram is not linear, but it is a web of interrelated concepts.

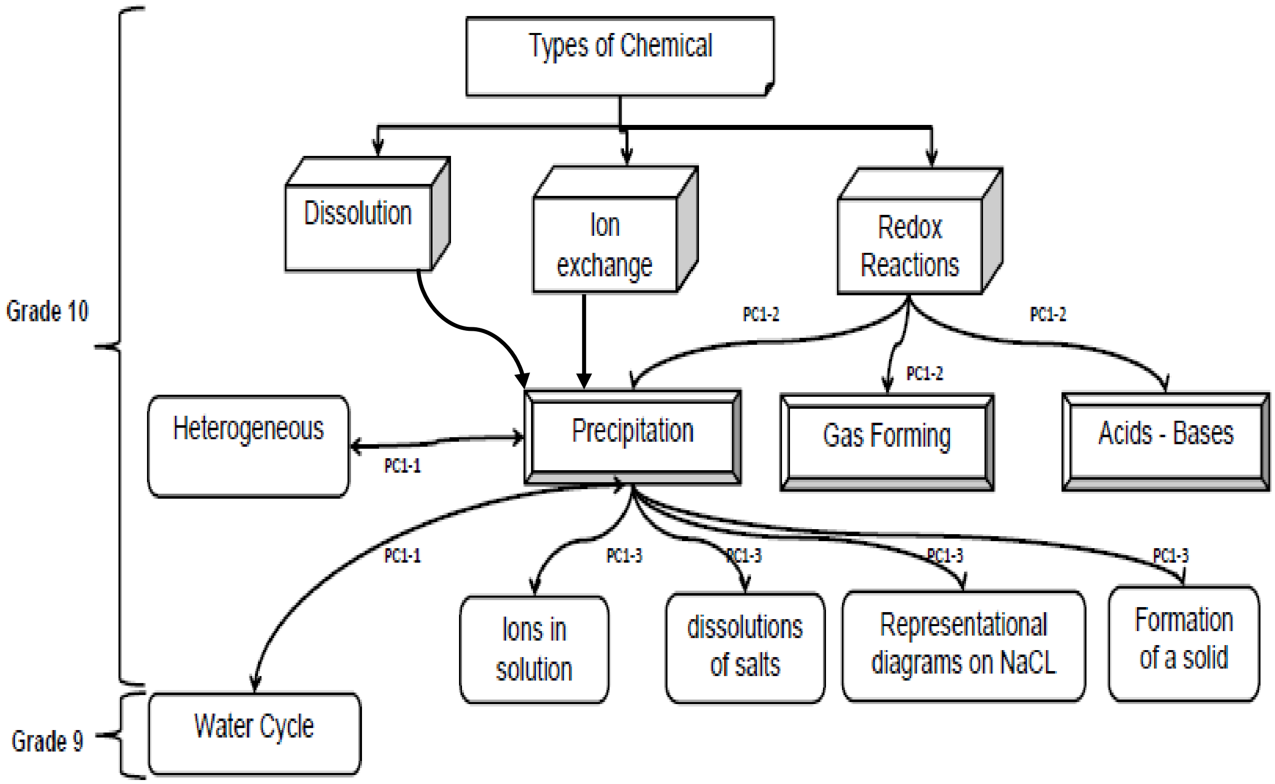


Figure 5.3: Concept Low diagram for Mr Johannes

The teacher presented concepts in a systematic manner that showed prowess in linking concepts coherently. Learners were engaged though they were not given the opportunity to explain their contributions to ascertain the depth of their conceptual understanding. Nevertheless, in groups, learners fully engaged with each other. The excerpt below shows one of the group's discussions on the formation of silver chloride from silver nitrate and sodium chloride using microscopic representation diagrams on a worksheet.

70	*3rd*	*I think it is going to be solid*
71	*1st*	*Yeah*
72	*3rd*	*But how is doing it*
73	*1st*	*He said we should draw a diagram to show how to represent AgCl*

73	*2nd*	*How, in our notes?*
74	*1st*	*Yeah*
75	*4th*	*So silver nitrate it is going to continue, and it is going to be solid*
76	*3rd*	*yeah it might be solid*
77	*2nd*	*We can't just say solid*
78	*4th*	*We need to find the solution first*
79	*2nd*	*Yeah*
80	*1st*	*Isn't it going be*
81	*4th*	*Isn't it going to be what*
82	*1st*	*I am sure the ions exchange here*
83	*3rd & 2nd*	*Yeah*
84	*2nd*	*So, this…*
85	*1st*	*It will be silver chloride*

It is evident that the first learner was leading the argument and she could link ion exchange (meso scale, PC1-2) with precipitation reactions and correctly identified that Silver Chloride will be formed. In this excerpt, there is evidence that the first learner understood the concept of ion exchange and could solve the precipitation problem, in the process of helping her fellow learners. In this lesson, the teacher talk was eight minutes, teacher-pupil interaction was seven minutes, and group discussion was thirteen minutes. Mr Johannes's lesson can now be compared to Mr Zulu's lesson.

The two teachers were knowledgeable about the subject matter of precipitation. Both teachers quickly made links themselves instead of learners making the links on their own during their introductory part. The first vivid difference was the absence of group work in Mr Zulu's lesson. He spent thirteen minutes of the lesson on teacher talk and nine minutes on teacher-pupil interaction. His approach was teacher centred compared to Mr Johannes's approach that was learner centred. The second difference was in the number of concepts linked and the way they were connected. Mr Zulu's lesson concept interrelatedness structure was linear whereas Mr Johannes was hierarchical with several branches. Much cannot be said about learner understanding in Mr Zulu's class except that for Sessi who correctly did the dissolution homework exercise on the board. Other than that, the learners where not participative except for chorusing answers as a class. Whereas in Mr Johannes's class learners were participative, the one-word answers clouded teacher-pupil interactions. Learner-learner interactions were content rich and engaging in several cases the teacher was called to arbitrate on some disagreements.

Although, other teachers were bemoaning lack of time in their teaching Mr Johannes managed to do some activities and group work which learners frankly enjoyed and was very cooperative in those group discussions. Answering a probing question of why he could do so many activities in his lesson when other teachers were bemoaning lack of time? Mr Johannes explained his teaching approach and indicated that

> *It is all about preparation and keeping the learners busy. I take my time in finding activities that will make learners interested and at the same time address the content issues as per the content guideline. When the activities are exciting, learners pay attention, and I tend to move even faster and cover much content. If you have realised, the learner discussions cover a particular objective of the lesson which I will only repeat if learners do not comprehend. Otherwise, in most cases, they do understand, and that saves much time. However, I learnt that if I do it myself without these activities, learners will ask many questions because they are trying to comprehend through imagination and those questions retard your pace of content coverage. However, if they have seen it through participation or observation most learner questions are answered in those activities.*

From the Mr Johannes' viewpoint adequate teacher preparation is vital in saving the time of teaching. Preparation should also incorporate learner activities that solve misconceptions learners might have. In my observation, the activities were simple and to the point and learners tackled them with awe in most of the cases. Therefore, it is crucial for teachers to invest much of their time in preparation not only of the content but also plan for the activities that would help in explaining the content to be taught.

5.2.2 Grade 11 first lesson analysis

Mrs Ndebele was teaching a Grade 11 class at School D, which is a township school. She had just finished a significant topic of Acids & Bases and was moving on to Redox Reactions. Her first lesson was on Oxidation Numbers; the second and third lessons were on oxidation and reduction processes. Mrs Ndebele linked the lesson of Oxidation Numbers by differentiating it from the topic of Acids & Bases. The main point of the latter topic was on the transfer of protons whereas in Redox Reactions the central concept was the transfer of electrons. Before the lesson, learners were given handouts on the rules of how to assign oxidation numbers to individual atoms.

The first part of the lesson was a class discussion on the rules of assigning oxidation numbers to elements. During the discussions, the teacher gave examples of each rule while learners took turns in reading each of the seven rules of assigning oxidation numbers to elements. The discussion was followed by a video clip that summarised all the rules and working out a few examples.

In the last half of the lesson, learners were given class work which they discussed in groups, and the teacher moved around checking learners' work and assisting those who needed help. Each group had to choose a spokesperson who gave feedback on their assigned problem to the whole class. The lesson ended with replaying the video to consolidate the rules and skills to solve problems. At the end of the lesson, learners were given homework to further practice in the assigning of oxidation numbers. The teacher emphasised the importance of the knowledge of assigning oxidation numbers to elements as they are essential in tracking the movement or transfer of electrons. Now let us look in detail how the scientific story of oxidation numbers was developed through link-making.

As can be deduced from Table 5-1, a total of 17 links were made in the first lesson of Mrs Ndebele (PC1-1 = 13; PC1-2= 1: PC1-3 = 3). About three quotas of it were micro scale, which was mainly referenced to oxidation rules that were discussed at the beginning of the lesson. The only meso scale that was used in the lesson was that of linking the topic of Redox Reactions with that of Acids & Bases as mentioned above.

The incoherence of these consecutive topics in the syllabus is evident in the implementation stage because they do not have any connections other than the transfer of protons and electrons, which the teacher expertly linked. It also denotes irregular organisational aligning of interrelated topics. Hence, the absence of the meso scale in this first lesson. Although the macro scale was limited in this lesson, the teacher did her best to connect the concept of Oxidation Numbers with concepts like the periodic table covered in Grade 10 and Chemical Bonding covered in Grade 11.

The teacher did not foreground these topics in her introduction. Nonetheless, she referred to them as her lesson progressed as each rule was discussed and that proved to be of importance to the understanding of the lesson. In the excerpt below, the teacher and the class were discussing rule two which a learner by the name Neo was reading.

Turn	*Speaker*	*Transcription*
17	*Neo*	*The monoatomic ions with only one element.*
18	*Tr.*	*….. looking at monoatomic ions these are elements which have got one type of an atom ne. Remember we did this end of second term ne.*
19	*Class*	*Yes*
20	*Tr.*	*Monoatomic that means it consists of how much. It consists of one, then continues over there.*
21	*Neo*	*A type of atom with an oxidation number that is equal to the charge.*
22	*Tr.*	*Yes, so we are saying we are looking at monoatomic it has an element of one, and we are saying number one we said it neutral ne?*
23	*Class*	*Yes*
24	*Tr.*	*Now we are saying it consisting of a charge; it takes us back to group one, remember group one and 2, yes. So, we are saying if you are looking at sodium, sodium is in the group what.*
25	*Noma*	*It is in group one*
26	*Tr.*	*It is in group one ne.*

27	*Class*	*Yes*
28	*Tr.*	*That is, it will be a $Na^{+,}$ and when you are looking at magnesium in group 2, it will be an Mg^{2+}. When you are looking at chlorine and remember chlorine is in the group what*
29	*Steven*	*Seven*
30	*Tr.*	*In group 7, it will be a CL^{-}, it is a halogen ne. Fine, then let's move on to rule number 3.*

Mrs Ndebele was identifying relevant links, which the learners connected successfully during the discussion. Foregrounding the periodic table concept at the beginning of the lesson was imperative, as learners would know from the onset the ideas that were central to the grasping of the concept at hand. In turn 18, the teacher indicated that monoatomic substances were discussed in the second term (3 months before this lesson) but did not give learners a chance to explain or try to recall what was discussed then about the concept.

As a result, she missed an invaluable opportunity to evaluate learner understanding of this concept by asking learners to describe what they still remember. However, Noma and Steven in turns 25 and 29, respectively, could recall the groups of sodium and chlorine, a topic that was covered in Grade 10. Mrs Ndebele used this strategy of identifying possible links as the lesson progressed throughout the discussion of the seven rules used to assign oxidation numbers. Overall, four macro linking-making concepts were made in the lesson that included monoatomic elements, groups of the periodic table and chemical bonding. Now let us look at her teaching style or methods that were used in teaching for conceptual understanding.

Mrs Ndebele used question and answer, video clips, group discussion and learner presentations methods to delivers her lessons. During the whole class discussion, she paused questions on concepts that she knew learners had prior knowledge. In most cases, learners were only asked to connect the teacher's identified links without explaining in detail their understanding of the concepts. Take for example turns 24 and 25 on the above excerpt where the teacher was describing why sodium had a charge of plus one because it is in group one. The teacher could have asked learners why all elements in group one are assigned a plus one charge to evaluate learners' deep understanding. Giving learners a chance to support their connections with scientific evidence would have assessed their comprehension of the concept.

Moving on to the use of the video clips, Mrs Ndebele had to choose from preloaded video clips from the smart board that summarised all the rules of assigning oxidation numbers to elements, which also had worked out examples. The method aided learners who did not understand the teacher's initial explanation as some learners were heard passing on approval comments such as 'now I get it' and 'it is now clear to me'. After the video, the learners were given the task to work out individually before the group discussions.

During the group discussions, the teacher moved around evaluating learners' work and assisting where learners were having problems. In some instances, when she discovered misconceptions, she would address the whole class. For example, learners could not differentiate when oxygen has an oxidation number of -1 or -2, and she addressed the whole class by giving them examples of peroxides where oxygen had the oxidation state of -1. The learners' presentations on the board exhibited a deep understanding of the concept as they solved the problems giving good reasons for their steps, as shown in Lisa's presentation below.

Turn	*Speaker*	*Translation*
98	*Lisa*	*Sodium chloride is a neutral, a neutral compound, so we know that the overall oxidation number of the compound will be equal to zero. Sodium has an oxidation number which equals to positive one because it is in group one, so chlorine has an oxidation number of positive minus one. (Lisa working on the board)*

$$x + (+1) = 0$$

$$x + 1 = 0$$

$$x = -1$$

Lisa demonstrated an understanding of working out problems of neutral compounds by first assigning sodium element an oxidation state of +1 because all elements in group one have an oxidation state of +1. The presentations gave learners an opportunity to explain to their peers their understanding of the work under discussion. Mrs Ndebele concluded her lesson by giving learners homework about more problems with assigning oxidation numbers. I will now analyse Mrs Meyer's lesson, which also begins with the same topic of Oxidation Numbers. However, the two teachers' approaches were entirely different.

Mrs Meyer taught both Grade 11 and 12 Physical Science classes at a suburban school B, a former model C school. Although the school was in a suburban town most of the learners were from the townships, and one of the townships was where school C was located. As a matter of fact, schools C and D were in the same town area, and the majority of the learners were from the same catchment area.

School D had a boarding facility with a capacity of 90 learners, constituting 9.4 % the school population of 960 learners. The boarding learners came from three different provinces, namely Mpumalanga, Free State and Gauteng. However, most of the learners were from the township suburbs.

In her Grade 11 Physical Science class, Mrs Meyer was teaching the same topic as Mrs Ndebele on Redox Reactions and the previous set of lessons was also on Acids and Bases. As indicated in Table 5.1, Mrs Meyer managed to make links to promote the scientific story as follows PC1-1 = 18; PC1-2= 3: PC1-3 = 19, making a total of 40 links more than twice that of Mrs Ndebele. Just like Mrs Ndebele, she had few meso scale links for the same reason that teachers hardly found any links from the preceding topic of acids and bases. Contrary to Mrs Ndebele, Mrs Meyer had a very high score of on both macro and micro scales, how she managed this will be discussed in the coming paragraphs. Nevertheless, the macro scale linkages were prominent in the introductory part of her lesson.

In her concluding lesson of acids and bases, Mrs Meyer introduced learners to the rules of assigning oxidation numbers but did not discuss them in detail. Learners were given the task as homework. In her introduction to the first lesson on redox reaction, Mrs Meyer did not mention Acids and Bases as Mrs Ndebele did. Her focus was on introducing the terminology associated with Redox Reactions and reminding learners where they encountered concepts related to this topic before. Hence, her macro scale linking was very high compared to Mrs Ndebele's, as shown see extract below.

Turn	*Speaker*	*Transcription*
1	*Meyer*	*……….We are going to do just a little bit of your terminology. So that I can see if you know anything already and if you can remember a few things because we did discuss this topic somehow. So, you have got some ideas about what is going on. Remember that redox reaction they fall under electrochemistry. Who can explain what electrochemistry is all about? What does the word tell you? Come anybody do not be shy. I know some of you want to say something. Yes.*
2	*Pardon*	*Does it have to do with electricity?*
3	*Meyer*	*Yeah and the rest of it?*
4	*Praise*	*Chemistry*
5	*Meyer*	*Chemistry ne.*
6	*Duncan*	*Chemicals.*
7	*Meyer*	*Chemicals that make electricity possible, chemicals and electricity. The next question is who knows what electricity is, anyone?*
8	*Ntombi*	*Is it not current*
9	*Meyer*	*Yeah, but what is current*
10	*Ntombi*	*It is I*
11	*Meyer*	*Yeah, but that is a symbol think about it microscopically. What is happening inside a wire? What is electricity what is it? Do you want to say something?*
12	*Clarice*	*I know*
13	*Meyer*	*What is it?*

14	*Clarice*	*The movement of electrons.*
15	*Meyer*	*The movement of electrons or the movement of charge. Awesome you do know, but you scared to say. Good for having the courage. All right, it is the movement of electrons in an atom. Where is it inside the outside the nucleus?*
16	*Class*	*Outside*
17	*Meyer*	*Outside, in the orbitals around our nucleus. Remember we were looking at these models in Grade 10. You have even drawn Aufbau diagrams ne. To show energy levels and where the electrons are.*

The brainstorming at the start of the lesson linked learners to the basic concepts of electron flow and the teacher was mainly concerned with reminding learners about where the topic of Redox Reactions emanated from. In the extract above, the teacher linked the Physics topic of the flow of current with the movement of electrons in atoms from Chemical Structure and Bonding. Learners did not disappoint as they remembered and linked concepts the teacher intended them to bring forth to grasp the discussion on Redox reactions. The exercise was an opening session to an array of other concept linkages such as Ionic Bonding, Periodic Table, electronegativity and other topics as indicated in Table 5.1.

Mrs Meyer's first lesson was rich in macro scale link-making for she foregrounded those relevant concepts to Redox reactions from previous Grade 10, 11 and even from Grade 9. However, unlike in the introductory part where learners were involved in the brainstorming class activity, Mrs Meyer adopted a transmission teaching style. She indicated areas where links could have made and connected the links herself. Learners only agreed as a class to her sentiments without giving their contributions, and their thinking, see shown in the excerpt below.

Turn	*Speaker*	*Transcription*
29	*Meyer*	*When an element or atom gains electrons what kind of charges are electrons positive or negative*
30	*Class*	*Negative*
31	*Meyer*	*An element when it is neutral it has equal amounts of protons and electrons and*

they cancel each other out neutral completely. But when it gains electrons what charge will it have

32	*Class*	*A negative charge*
33	*Meyer*	*A negative charge because it will not have extra negatives which will tip the seal it be neutral anymore it will have extra it will be a negative ion now since we have the picture of the rusting of ions lets quietly see what the reaction work like when iron rusts. I need oxygen to next and then it's going to make iron oxide there is to reaction making iron oxide we are going to look at this one iron is going to react with oxygen to make iron oxide. Now we need to decide is it a Redox Reaction? It is, but we are going to tell you why* *It is a Redox Reaction look at iron it's a metal, and we said something about metals you in Grade 10. What kind of ions do metals make do they make positive?*
34	*Arnold*	*They make positive*

Class discussions were minimised in the first half of the lesson, and the teacher talk took centre stage. Hence, Mrs Meyer could score highly on both micro and macro scale link-making than Mrs Ndebele and any other teacher for that matter. In Mrs Ndebele's lesson, each segment of activity was followed by group discussions that facilitated group deliberation and consolidation on what was presented by the teacher. In contrast, in the first half of the lesson, Mrs Meyer did everything for the learners from identifying the links and connecting them herself to doing examples of how to calculate oxidation numbers. She saved the group discussions for the second half of the lesson after she had laid down all the necessary concepts learners needed to know. In the group discussions, that is where the micro scale link-making was prominent as learners referred to the concepts such as the rules, transition elements and the periodic table that were covered in the first segment of the lesson. During the group discussion, the teacher was troubleshooting as she moved from one group to the other, clarifying unclear concepts and arbitrating on learner arguments. As in Mrs Ndebele's class, the group discussions centred on assigning oxidation numbers to elements in a compound using set rules. An extract below shows one group working on polyatomic ions and the teacher was called upon to assist.

Turn	*Speaker*	*Transcription*
189	*Karabo*	*So, chromium should not be equal to zero*

190	*Meyer*	*Not to zero because it is polyatomic so all the numbers must add up to*
191	*Karabo*	*Negative 2*
192	*Meyer*	*And for the bottom, all the numbers must add to minus*
193	*Karabo*	*One*
194	*Gift*	*Ma'am Chromium is a Transition metal*
195	*Meyer*	*It does not have a rule we have to*
196	*Gift*	*Calculate it, but I remember it says transition metals are given a name*
197	*Meyer*	*If it has given a name, but you are not given a name*
198	*Gift*	*Ooh ok*
199	*Meyer*	*So, since we don't have the name of it, we must calculate it*
200	*Gift*	*But it must add up to minus two*
201	*Meyer*	*Yes, it's a polyatomic ion, look you have got, where is it, you have seven oxygens you can work out the charge it must be equal to*
201	*Group*	*Minus two*

The learners sought clarity on how to work out the oxidation number of chromium (Cr) element in chromate ion (CrO_4^{2-}). The confusion aspect of the transition elements was that other elements were written as iron (II) chloride and learners were taught that the oxidation state of iron in this case would be +2. Hence, Gift was expecting chromium element to be assignment a roman numeral number that will indicate its oxidation state. Mrs Meyer then indicated to Gift and his group that they should use other elements with known oxidation numbers to calculate the Chromium oxidation number.

The teacher had to go over the concept again for the learners to understand. This was the kind of troubleshooting the teacher had to go through during the group discussions. Most of the concepts she had s covered in the first half of the lesson were not understood by some of the learners, and she had to repeat them to individual groups according to their needs. However, some groups were able to get the explanations from the onset, and the teacher allowed them to assist in explaining the concepts to the other learners.

Unfortunately, the learner who helped clarify the problem of polyatomic ions to most learners was not comfortable to be recorded; hence there is no record of her conversation with her peers. However, it could be observed that learners understood her explanations through their appreciation of her contributions. Despite using the most resented teaching style in the first segment of her lesson, Mrs Meyer's style of teaching in the second segment proved to be useful and effective as most learners could solve problems either with the help of the teacher or with that of peers.

Mrs Meyer's approach of first covering the concepts in detail through transmission method with limited learner contribution and then later allowing learners to discuss in groups was consistent throughout her lessons even in Grade 12 classes. Giving much time to discussions contributed to the high score of scales of linking especially the micro scale. The diagram below summarises the nature of her link-making throughout the first lesson.

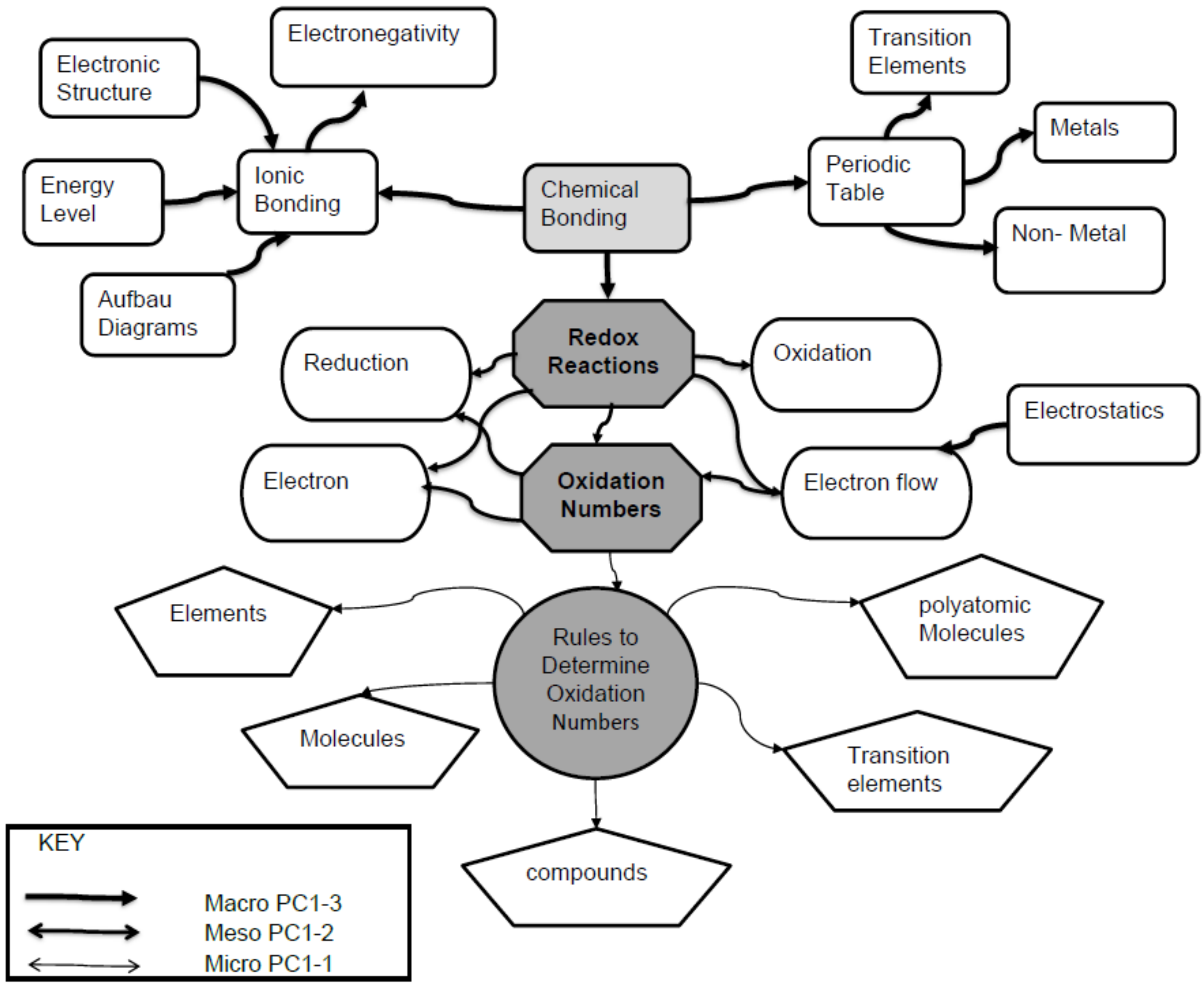


Figure 5.4: Conceptual network deduced from Mrs Meyer's Grade 11 first lesson

The conceptual network above summarises how Mrs Meyer interlinked different topics from different Grades across the Physical Science curriculum. The primary learning area that was significant to the Redox Reactions was Chemical Bonding, the concepts that took centre stage emanated from the periodic table and ionic bonding. In the first lesson rules to assign oxidation numbers and calculation of oxidation states of elements was the focus of the lesson. Therefore, the scientific story of Redox Reactions was developed and built upon the concepts of periodicity and ionic bonding. The topics on ionic bonding and periodic table were the underlying concepts Mrs Ndebele used although she included Acids and Bases which Mrs Meyer never referred to. The former did not get into the detail of how the concepts in these topics were linked to the Redox Reactions, as shown in

Figure 5.5 below. Mrs Ndebele linked these topics to Oxidation numbers whereas Mrs Meyer linked them to the topic of Redox Reactions, which was then connected to Oxidation numbers. The omission of Redox Reaction as a central concept in Mrs Ndebele lesson developed a gap between oxidation numbers and redox reactions, which did not give a full scientific story that is needed for conceptual understanding.

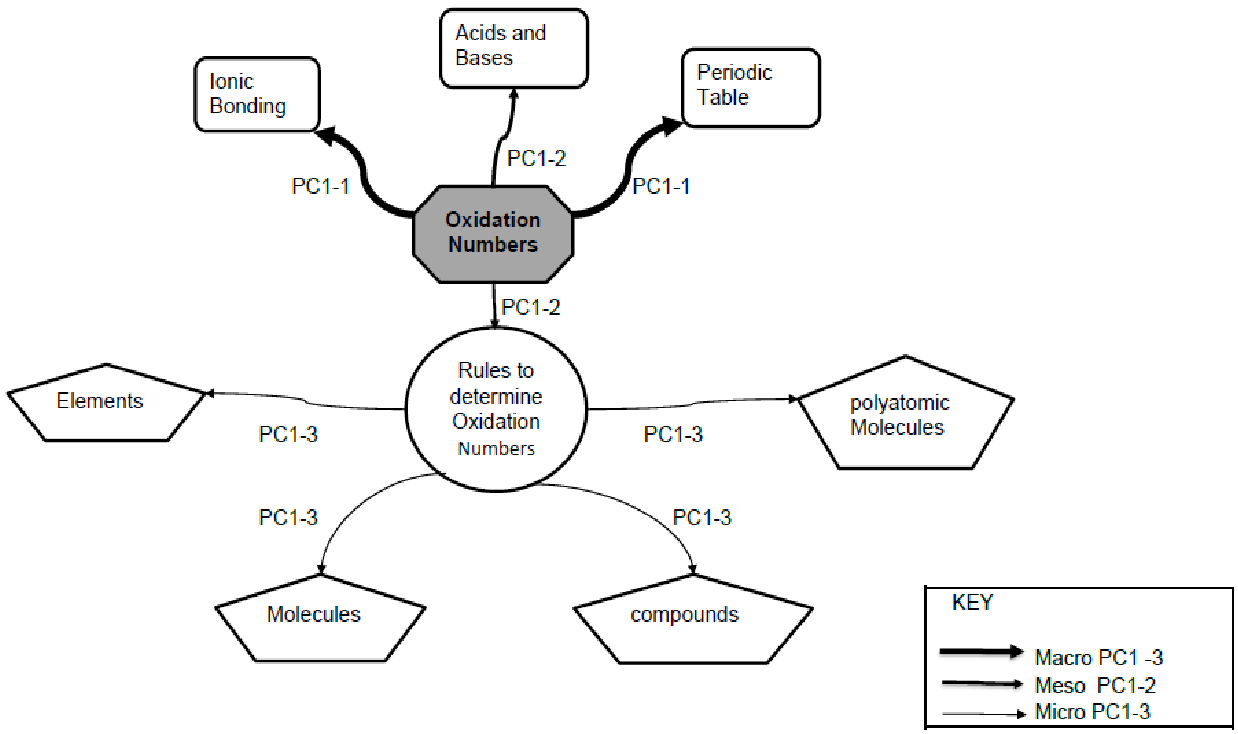


Figure 5.5: Conceptual network deduced from Mrs Ndebele's Grade 11 first lesson

The two teachers treated the concept of oxidation numbers the same. They both covered strategies of solving problems of finding oxidation numbers of elements in simple molecules, compounds and polyatomic substances. However, Mrs Meyer went further and covered transition elements with variable oxidation numbers. From analysing Grade 11 lesson, it is evident that the broader the conceptual network of a topic the more the link-making there is. However, the understanding of the concepts by learners depends on how the teachers present the lessons. Let us now look at how Mrs Meyer executed her Grade 12 lessons.

5.2.3 Grade 12 First lesson analysis

In Grade 12, Mrs Meyer was teaching Electrolytic Cells, a topic that comes after one on Photoelectric effect, according to the Department of Education Work Schedule. Photoelectric effect is a concept under the learning area of Optical phenomena and properties of Matter and Materials, which is different from Chemical Change. The last portion of Chemical Change had been done in term 2, which was three months down the line. Hence, it was found out that both Grade 12 teachers did not have meso scale link-making in their first lessons.

Like in the Grade 11 first lesson, Mrs Meyer introduced her lesson through brainstorming; reminding learners where and when they encountered concepts linked to Electrolytic Cells. She briefly discussed the concepts of Redox Reactions (see extract below) and moved on to deliver the rest of the lesson through transmission method.

Turn	*Speaker*	*Transcript*
3	*Meyer*	*You started with these types of reactions already last year, so it's not brand new to you. You did redox and oxidation reactions now I am already throwing those words out hopefully to spark some memory ok. Let's see if we can get those juices flowing. Who can still remember what oxidation is and what is a reduction? Do you have any idea what oxidation and reduction is?*
		Thabo
4	*Thuso*	*Oxidation is the loss of electrons.*
5	*Meyer*	*Loss of electrons is oxidation very nice and then what is a reduction*
6	*Natty*	*The gain of electrons*
7	*Meyer*	*The gain of electrons. Well you guys had a great teacher last year I'm glad you still remember*
8	*Class*	*Class laughs*

As can be deduced from the above extract, learners knew about what they had done approximately 11 months ago. They gave answers to the teacher's questions without hesitation and with teacher probing. Nonetheless, the teacher did not allow further discussions about the topic.

Unlike in Grade 11 classes where the second segment was class discussion, in this lesson Mrs Meyer used the transmission method and played a video clip. She did not allow discussion in groups. Learners were not invited to contribute and if they did in most cases, it was chorus answers. However, the discussion on this topic was done in the second lesson that took place the next day as the first lesson was shorter due to one test period that was done for the whole school in the morning.

During the teacher interview, Mrs Meyer reiterated the fact that the syllabus was congested, and she had to rush it, for learners to get into preliminary examinations having done all the stipulated topics. She thought that covering the syllabus meant saying everything to the learners and making sure everything is in their books so that when book controls were done by the authorities the work, would be appearing in the learners' workbooks. The DBE, through the district officials, wanted a report of syllabus completion. Hence, she felt complied to rush through the syllabus and complete it at the expense of learner understanding. Consequently, in this first lesson, most of the links were done by the teacher.

Mrs Meyer managed a total of 16 links (PC1-1 = 7; PC1-2= 0: PC1-3 = 9) compared to 40 she did in the first lesson in Grade 11. The comparison of the links made by the teacher and learners are discussed later in this chapter. Just like in her Grade 11 lesson, Mrs Meyer made more links on the macro scale than with micro scale. All the topics referred to in the macro scale were from Grade 11 Redox Reaction topic as indicated in Table 5.1 and these included electron transfer, reduction, oxidising agent, reducing agent, etc. (see Figure 5.6).

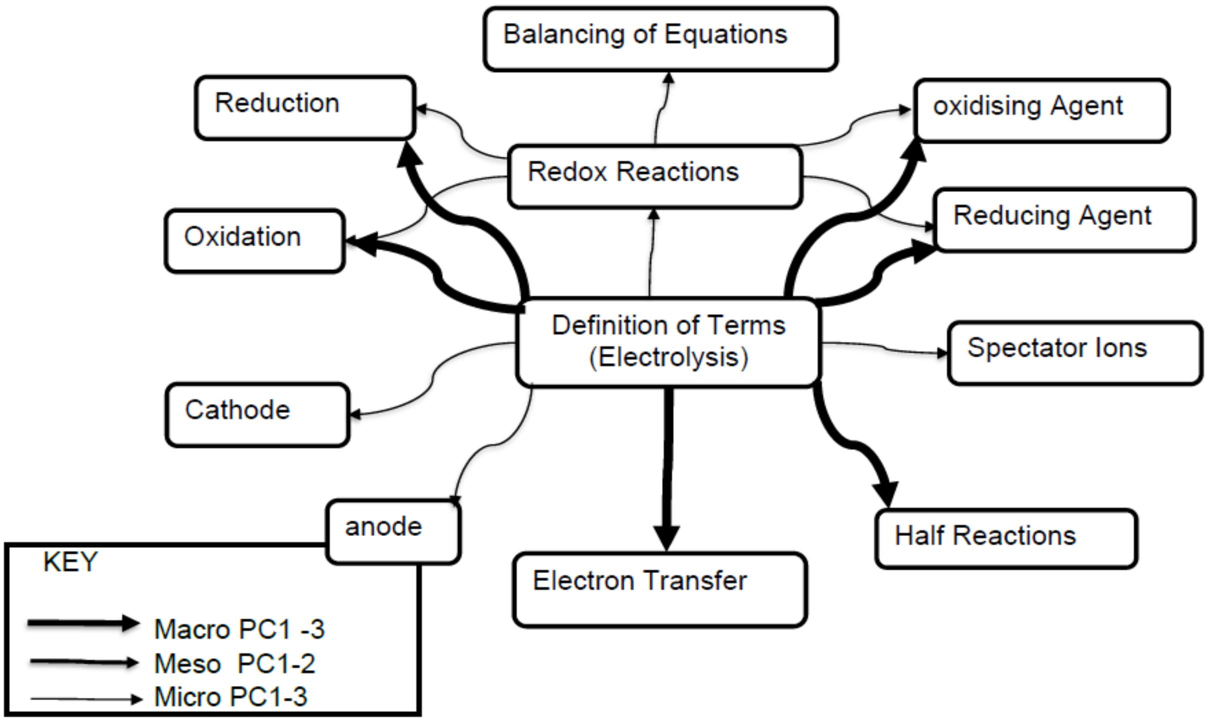


Figure 5.6: Conceptual network deduced from Meyer's Grade 12 first lesson

There were no new concepts that were to be dealt with on the topic of Electrolytic Cells. Except for the concept of microscopic, the invisible reaction takes place at the interface of the electrode and the solution in the electrolytic cell. The other new concept was the identification of half-reactions taking place at the anode and cathode as well as the application of electrolysis. The video that was shown to the learners was supposed to help in bringing comprehension of the phenomena of redox processes at the electrodes. Surprisingly, the teacher did not allow any discussion of what the learners had seen and heard from the video (see the excerpt below).

Turn	*Speaker*	*Transcription*
30	*Meyer*	*So, this is what we saw, we saw iron being a solid, giving away electrons and becoming aqueous because it dissolved basically in the solution. Am I right, and why did it become an ion in the process because it gave away electrons? So, giving away electrons, or losing electrons means that you are being oxidised. Is that correct? So, iron was oxidised. Now what happened to the copper, the copper was an ion, it dissolved that is why it gave that pretty blue colour it was liquid. It was still in its ion form, so the copper was aqueous, but then it took the two electrons that*

		iron was giving away and what happens is that it was reduced, and it became a solid which then stuck to my iron nail. The copper became solid, and that means that copper was reduced because it gained electrons. Now I want to see if you guys can put two and two together, I am going to ask you between the two of these which one is the reducing agent?
31	*Cl*	*Mumbles opinions*
32	*Meyer*	*I hear some iron over there. Who is saying copper?*
33	*Cl*	*Raises hands*
34	*Meyer*	*Who is saying iron?*
35	*Cl*	*Raises hands*
36	*Meyer*	*I see a few hands. So, the rest of you are not sure. Who is saying iron*
37	*Cl*	*Mumbles and raises hands*
38	*Meyer*	*I see a couple more hands, yeah you must be sure. Iron is our oxidising agent… reducing agent.*

The fact the learners were not even confident in raising their hands meant that the concept was not clear to them. The class was divided as some identified copper as the oxidising agent and others chose iron. But no clarification was sort from learners to get the misconception of those who chose copper over iron as the oxidising agent. In turn 36, the teacher saw few hands, when she asked how many say iron, of which it was the correct answer. That on its own should have alerted the teacher that learners did not understand both her talk and the video clip. Continuing to more abstract terms was going to be even difficult for learners to copy as more abstract concepts were covered without a sound base of the essential concepts.

Mrs Meyer’s approach was entirely different from her Grade 12 counterpart in School E, Mr Masutha. School E was in a low-density suburb in a different town from School D. However, the two schools shared the same feeder areas as most learners from School E were from township suburbs as well. Their laboratories were built with the same format as all were former model C schools and the two schools had limited resources.

Mr Masutha was teaching Electrolytic Cells to the Grade 12 learners, but his first lesson was concisely 15 minutes. The reason the lesson was that short was because all Grade 12 learners were called to the hall to be addressed by the district officials on their preliminary examination preparations. However, the theme of the lesson was on the definition of terms that were associated with the process of electrolysis in an electrolytic cell. The teacher used the question and answer technique. Unlike in Mrs Meyer's classes where the teacher only asked questions, in Mr Masutha's class learners could ask questions the moment they encountered a problem. As an observer, I could see this as the culture in Mr Masutha's classes because throughout the three lessons observed learners interjected the teacher talk with questions which the teacher fully addressed without a problem.

During the interview, Mr Masutha argued that there is no need to continue with the lesson if one learner does not understand the concept. He encouraged his learners to pause questions where they did not understand. The episode below captures such a moment in that short period where a learner showed that he did not understand the concept of green salt.

Turn	*Speaker*	*Transcript*
3	*Masutha*	*I am going to demonstrate each of the processes one by one. With me here I have got Copper II chloride, it is a salt*
4	*Thandi*	*Salt?*
5	*Masutha*	*It is salt all ionic salts can be decomposed right not the salt you eat, isn't it?*
6	*Thandi*	*Is there a green salt?*
7	*Masutha*	*There are many types of salts; some are edible some are not so this one is one such that is not edible. If I take this salt and I apply enough Heat to it, it will melt and form a liquid salt. Do you understand? that liquid will be able to conduct electricity, or if I take this salt dissolve it in the water, I will make a solution of this (raising the copper (II) salt in a beaker) this solution will conduct electricity, and I will call this salt solution an electrolyte. It will also be decomposed by the electric current. What do I mean by decomposition*

8	*Tebogo*	*broken down*
9	*Masutha*	*broken down into its elements, remember this is copper II chloride is made up of copper ions and chloride ions….*

After clarifying that some salts are edible, and some are inedible, the teacher went on to explain how conducting substances are made in the form of a molten and aqueous solution. Aqueous solutions and solution conductivity were dealt with in Grade 10 and Grade 11. However, there was a conceptual gap of electrolytes (the conducting solutions) in Grade 11. Hence the teacher had to link the concepts done in Grade 10 with the Grade 12 work. Bridging the electrolyte conceptual gap was the missing link in Mrs Meyer's first lesson and it this concept which learners have difficulty in understanding, especially the movement of electrons from one electrode to the other. Mr Masutha explained the concept of how electrodes conduct current into electrolytes, as shown in the extract below.

Turn	*Speaker*	*Transcription*
21	*Masutha*	*So, we have two electrodes; this can be the anode and this one a cathode or vice versa depending on how I connect to the power supply. Right so we will be using an electrode, what is an electrode*
22	*Lennox*	*An electrode is a device which allows current to enter or leave the electrolyte.*
23	*Masutha*	*Correct. Remember current flows from which terminal of the battery*
24	*Lennox*	*positive*
25	*Masutha*	*So, if the electrode was not dipped into the electrolyte do you think the current will be going in this direction*
26	*Class*	*No*
27	*Masutha*	*So, this electrode enables the current from the battery to get into the electrolyte and then this other one will allow the current to leave to go outside the electrolyte. That is why I am saying the electrode, in general, enables current to enter the electrolyte remember the current is moving in this direction that is the function of the electrode. How many types of electrodes do you know?*

Lennox, in turn 22, defined an electrode even though the concept was done in Grade 10. In turn 24, he was also able to identify the direction of current from a battery. As the concept of electron flow into the electrolyte was being developed through class discussion learners had problems in identifying the flow of ions to the cathode and anode.

Nevertheless, Mr Masutha did break the impasse by explaining the movement of negative ions to the anode and positive ions to the cathode. Unfortunately, the lesson was cut short as learners were called to the hall. Mr Masutha never used group discussions. During his interview, he indicated the issue of time as he was compelled to finish the syllabus. He also reiterated the fact that the syllabus was congested, and he had to conduct Saturday classes for him to finish the syllabus. Consequently, his teaching style was mostly the use of question and answer and experimental demonstrations. In all his three lessons, Mr Masutha did experiment demonstrations, which he conducted together with the learners, he did not use any group work. Mr Masutha was asked why he did not use group work in all his lessons, to which he replied;

> *With the grade 12 learners, there is no time to take chances of giving them group work. In group work no matter how guided it is you will find one group which will not do its work. Once they are behind that is it, for them to catch up with the concepts will be a big task. So, to avoid that I prefer whole classroom discussions where I will monitor the progress of the discussion and the substance of the debate. At the same time, I will be tracking my time of completing the syllabus.*

As can be deduced from the extract above the objective of the teacher is to complete the syllabus with minimum disruption where possible. Hence, the teacher had to find the means by which he can complete the syllabus. Interestingly, the majority of the teachers did not employ traditional methods. Most of the teachers indicated that they only adopt the transmission method as the last resort when they are desperate to finish the syllabus.

Due to the limited time in this lesson, Mr Masutha managed a total of nine links PC1-1 = 4; PC1-2= 0: PC1-3 = 5, of which macro scale had more links than micro scale. Like Mrs Meyer’s lesson, Mr Masutha did not have any meso scale link-making for the same reason that the previous lessons were from the Physics learning area, which had no conceptual relationship with Electrolytic Cells. Most of the macro scale link-making was from Grade 10 concepts of dissociation and electrolytes, as shown in Figure 5.7 below.

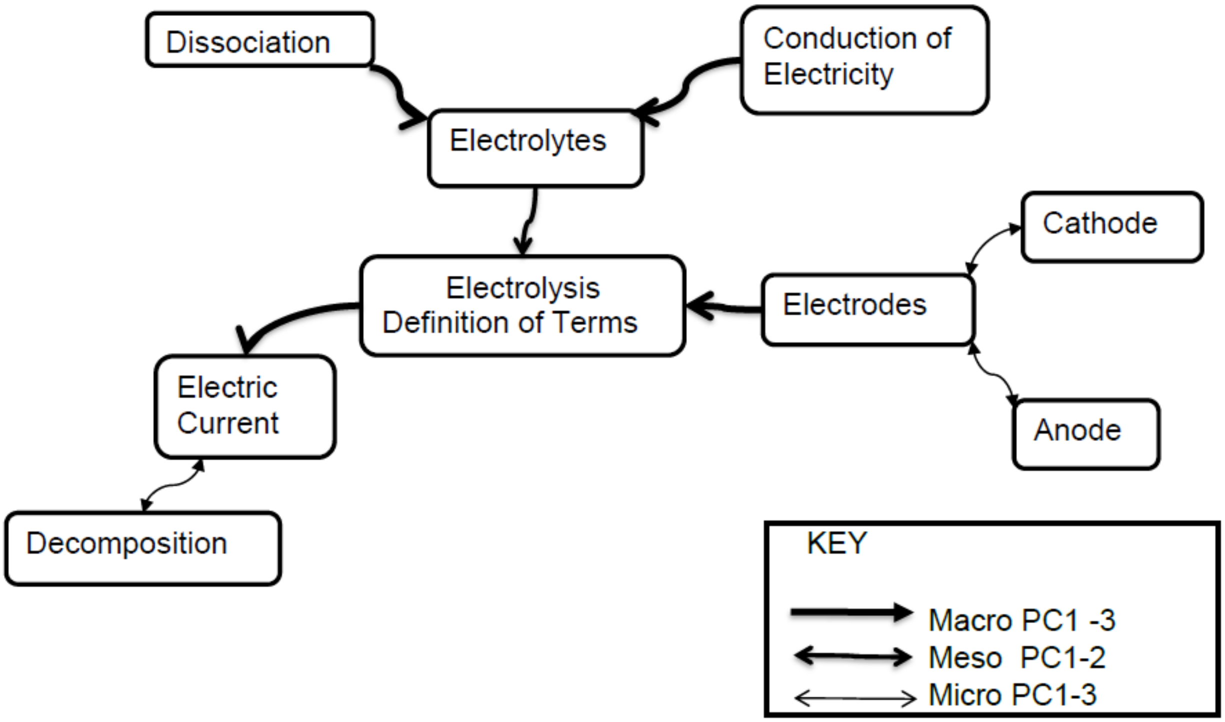


Figure 5.7: Conceptual network deduced from Masutha's Grade 12 first lesson

Unlike, Mrs Meyer who foregrounded concepts from Grade 11 Redox Reactions, Mr Masutha focussed on the concept of electrolytes, which is equally pertinent to the topic of electrolysis. The conceptual network above shows no mention of redox reactions in the first short lesson of Mr Masutha. The redox reactions were referred to in the second lesson. Most of the second lessons from all six classes observed were a continuation of the first lesson, and the meso scale was predominant. However, in this research, I was interested in examining how the teachers linked the first lesson of a new topic with other previous concepts and how they conclude their lessons. The next lessons to be analysed in detail are the third lessons of each teacher.

5.3 General analysis of lesson 3

Most of the participating teachers concluded their series of lessons on the third lesson except for Mr Zulu and Mrs Meyer (Grade 12) who overlapped to the fourth lesson. Mr Zulu had very short periods, because of the two periods which came immediately after assembly and he could not conclude his lesson in the third period. For an objective analysis, his third and fourth lessons were combined to be one lesson since it was a continuation of concept. As for Mrs Meyer, the Grade 12 fourth Lesson was not included in the analysis as she only revised the homework provided in the third lesson and went on to do the topic of Galvanic Cells which was not part of the research although it was fully recorded. In Table 5.3, on the next page, shows the frequency scores of link-making and the concepts discussed per teacher per grade.

Lesson 3 generally incorporated link-making of concepts from lesson one and 2. Mr Zulu, Mr Johannes and Mrs Ndebele are the only teachers who used the third lesson to summarise the discussions of the whole topic of their respective grades. Mrs Ndebele and Mrs Meyer further continued referring to concepts of macro scale. Hence, their macro scale frequency scores were higher than those of the Grade 10 and 12 classes. Table 5.3 shows the macro scale concepts and most of the concepts were supposed to be done in the first lesson as learners' background knowledge to Redox reactions. For example, Mrs Ndebele discussed the concept, of number line, electronegativity and chemical bonding, whereas Mrs Meyer discussed tests of different gases. The concepts were going to be more relevant if they were discussed in lesson one as they are an essential component part of redox reactions. Therefore, the two teachers presented an incoherent arrangement of concepts in their third lesson presentations. The Grade 12 teachers, Mrs Meyer and Mr Masutha did not even summarise the topic of an electrolytic cell at the end of the three lessons. Mr Masutha argued that most of his homework addresses the summaries of his lessons whereas Mrs Meyer indicated that the group discussions questions consolidated the main points of the lesson. The two teachers indicated that they would also be saving time to cover the content.

Table 5.3: Summary of links and concepts covered in lesson 3 by each teacher

Lesson 3 analysis						
Grade	**10**		**11**		**12**	
Teacher	**Johannes**	**Zulu**	**Ndebele**	**Meyer**	**Meyer**	**Masutha**
Pc1-1	6	3	8	19	5	13
Pc1-2	13	8	14	12	12	21
Pc1-3	3	1	6	8	3	1
Total	22	12	28	39	20	35
PC1-1	Ion exchange x 3	Ppt reactions x 2	Oxidation number x 2	Decomposition x 3	Electrolysis of Al	Electrolyte x 3
	Halogens	Word equation	Oxidation process	Electron transfer x 3	Bleaching agent	Blue copper solution
	Oxidation		Oxidation rules	Oxidation reaction	Cell-membrane	Electroplating x 3
	Reduction		Redox reactions	Rusting of iron	Chloro-alkali industry	Oxidation of copper
			Balancing of equation	Displacement reaction x 4	Half- reactions	Reaction on the cathode
			Reducing agent	Reducing agent		Anode reaction x 3
			Oxidising agent	Synthesis reaction x 2		Reduction process
				Redox reactions x 2		
				Balancing of equations		
PC1-2	Types of reaction	Testing for ions	Rules of ON x 5	Reduction & oxidation	Electrolytic cell x 4	Electrolytic cell x 2
	Ppt reactions x 4	Dissolution x 4	Redox reactions	Lion roars	Experiment write up x 2	Energy conventions
	Gas forming reactions	Nitrates are soluble	Oxidation process x 2	Electron transfer	Half-reactions x 2	Electrolysis x 2
	Acids and bases reactions	Gas forming reactions x2	Reduction process x 2	Decomposition	Redox reactions x 2	Oxidation of copper
	Definition of an acid		Acids and Bases	Reducing agent	Chlorination of water	Reduction process
	Neutralisation		Loss of electrons	Complex anions	Balancing equations	Electrodes
	Displacement reactions		The gain of electrons	Redox reactions		Half-reactions
	Electron transfer x 3		Half-reaction	Balancing of equations		Oxidation reaction x 2
				Oxidation numbers x 3		Reduction process
				Number line		Electron transfer
PC1-3	Group 17 or 7	Experiment write up	Metal oxides	Types of reactions gr10	Fertilizers Grade 12	Dissolution of salts Gr. 10
	Periodic table		Standard redox potential (Grade 12)	Metal & acid reactions Precipitation reactions	Hydrogenation Gr12	
	Balancing of equations		Balancing of equations	Testing for gases grade 9	Chemistry of hair Gr 10	
			Number line	Testing for oxygen		
			Chemical bonding	Testing for carbon dioxide		
			Electronegativity	Testing for hydrogen		
				Testing for metals		

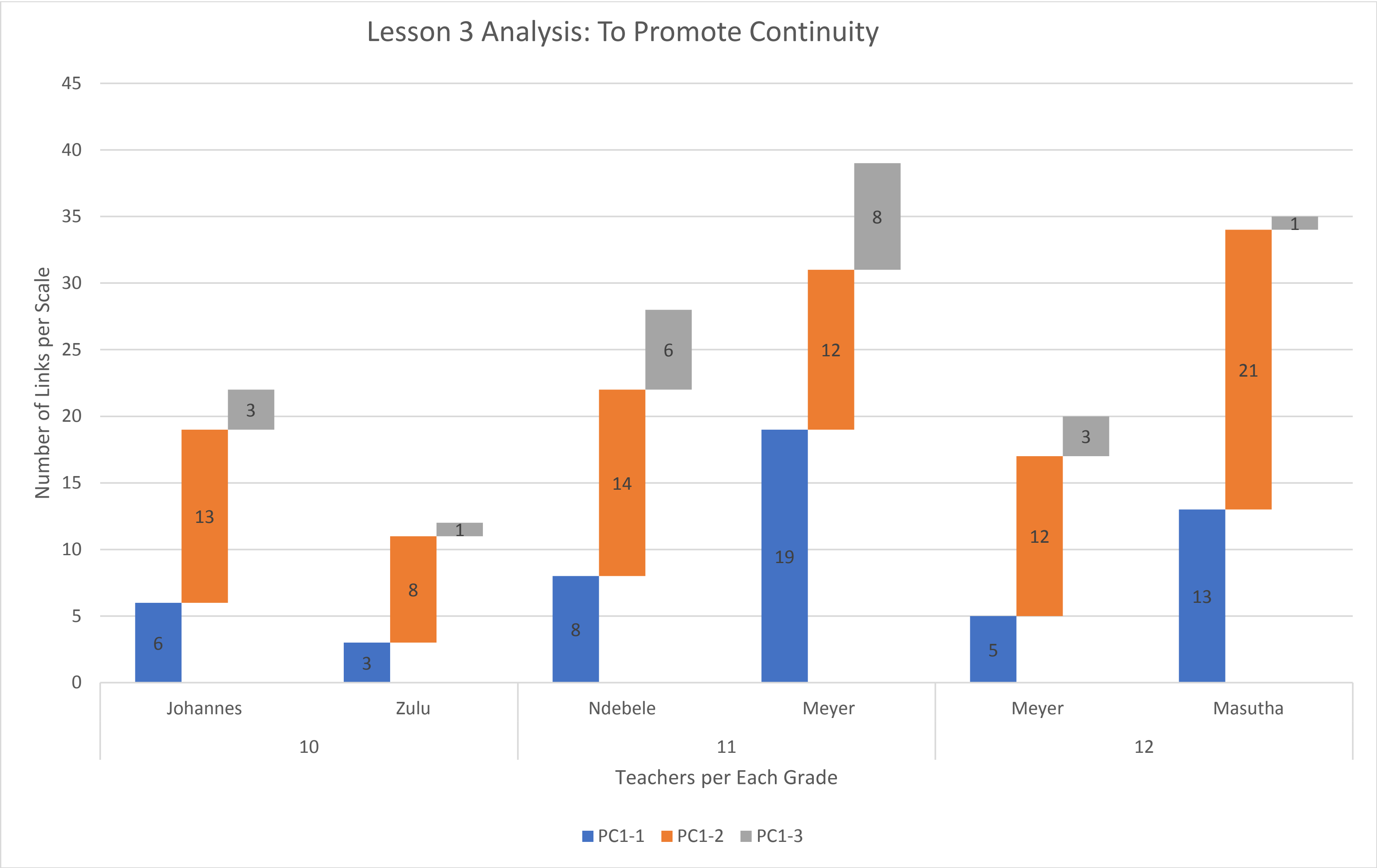


Figure 5.8: Different scales of link-making made by each teacher in lesson 3

As indicated in Figure 5.8 above, almost all teachers made more meso scale link-makings than any other link scale in the third lesson. Except for Mrs Meyer with her Grade 11 class, the micro scale was higher than the other two scales. The higher frequency score of meso scale link-making is quite significant as it indicated that teachers were making links with concepts of previous lessons separated by days. The relevance and importance of these links will be scrutinised when third lessons by each teacher are analysed. However, extensive use of meso scale was a good indication that concepts in the third lessons were being connected with previous lessons. The distribution of the scales of link-makings has no trend at all. The differences can be attributed to the prowess in linking concepts during the teaching process by the individual teachers.

Mr Masutha had the most links on the meso scale although he did not summarise her lessons. The high-frequency score in this Grade 12 classes can be associated with how the concepts of electrolytic cells are organised in the syllabus. The curriculum developers concluded the topic with applications of electrolysis, and each industrial process of the applications requires an understanding of all underlying concepts. Hence, the interlinking of concepts from all the lessons was inevitable, and teachers had to make the necessary link-makings. Therefore, ending a topic with applications or relevance to the concepts to industrial or everyday processes ensures learners are exposed to the holistic interlinking of the concepts, which has been treated separately.

5.3.1 Grade 10 Lesson 3 Analysis

The third lessons for the Grade 10 teachers were analysed by numerically counting the links made per each level of link-making to promote continuity. The concepts that were used to make the links were tabulated, as shown in Table 3.4 above and Figure 5.8 displays the differences in numbers for each scale of link-making through graphical representation.

Table 5.3 depicts that Mr Johannes used more links to promote continuity than Mr Zulu in all levels of link-making. He made a total of 22 links (PC1-1 = 6; PC1-2 = 13:

PC1-3 = 3) compared to Mr Zulu who made a total of 12 links (PC1-1 = 5; PC1-2 = 13: PC1-3 = 3). Although the two teachers were teaching the same topic (Reactions in aqueous solutions) the linking of concepts was entirely different as well as the teaching styles.

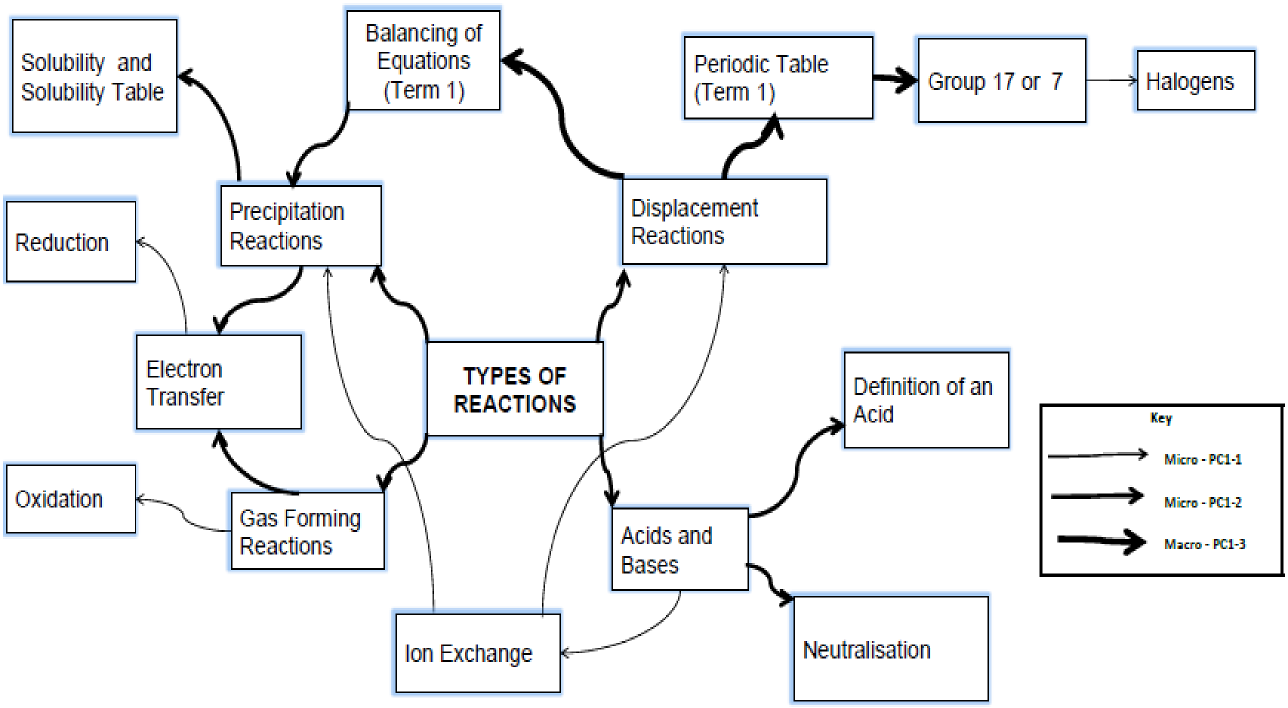


Figure 5.9: Conceptual network deduced from Johannes's Grade 10 third lesson

Mr Johannes used concepts from the first and second lesson to show how the current topic - Types of Reactions - was interlinked with the two previous lessons (Meso Scale). The interlinking of concepts was comprehensive. The teacher did not only show links to the learners but also allowed learners to complete the links. The teacher identified the links and learners made the connections as illustrated in the excerpt below when the class was discussing halogen displacement reactions.

Turn	*Speaker*	*Transcription*
89	*Johannes*	*…can you give an example of a halogen Petros, or what is halogen?*
91	*Petros*	*These are elements in group 17*
92	*Johannes*	*Yes, it is a group 17 element in the periodic table of elements, or you could simply say it comes from group 7 if you're referring to the old style.*

		Now, Kenneth, can u give an example of a halogen (silence from learner). Kenneth, you simply look at the periodic table of elements there and identified group 17.
93	*Kenneth*	*Chlorine*
94	*Johannes*	*Yes, we have chlorine and then, Yalo?*
95	*Yalo*	*Oxygen*
96	*Johannes*	*no oxygen is not in group 17,*
97	*Yalo*	*Chlorine*
98	*Johannes*	*we have got chlorine already what else?*
99	*Class*	*Iodine and Bromine.*
100	*Johannes*	*We have got iodine and bromine ne. So, when we are talking about halogen displacement, we are saying chlorine can be removed from solution by fluorine. Iodine can be removed from solution by chlorine…*

The teacher identified a possible connection between the periodic table and displacement reaction of halogens and led learners to do the linking by naming elements in Group 17. The teacher picked a learner who had forgotten about this concept, who said oxygen is in group 7, other learners who accurately identified bromine, chlorine, and iodine as elements in Group 17 corrected this. The teacher further used the periodic table to introduce a new phenomenon to the learners of the reactivity series of halogens, and he showed learners how chlorine could displace bromine in solution. When it came to balance equations, he led the discussion on how to balance the displacement equations.

The teacher was asked why he could not allow learners to do the balancing of the equations. He argued that balancing of the equation in Chemistry is an ongoing skill until grade 12 and at this stage; he did not want to waste time, as he will be behind with his work schedule. He further mentioned that the balancing of the equation was problematic to some of the learners as they had challenges in the first term, the time the topic was covered. On the macro scale, he used concepts covered in the first term and Reactions in Aqueous Solution was in the third term.

In contrast to Mr Johannes's ways of connection, Mr Zulu related the third lesson to the second lesson, and rarely did he refer to the first lesson. As depicted in Table 5.1

above, the linking was very minimum, and the teacher identified and made the connections himself without learner involvement. The teacher asked questions that would only draw chorus answers to agree with the teacher.

Turn	*Speaker*	*Transcription*
5	*Zulu*	*In the table of solubility, we discovered that not all substances are soluble in water, some are insoluble in water. There is another class of slightly soluble substances…… By slightly soluble, I can give an example of this one, (raising one of the test tubes) you can tell by the upper part that it is a bit clear than the lower part, correct*
6	*Class*	*Yes.*
7	*Zulu*	*Meaning to say even that clearness it is like, it's colourless, there are still some pockets of the substance that have not dissolved. So, we call such as substance slightly soluble, or partially soluble, right. We know that from the table all nitrates are soluble. Is that so?*
8	*Class*	*Yes*
9	*Zulu*	*………… All nitrates are soluble number 1, and all metal oxides and hydroxides are soluble except for those in group 1 and group 2, right?*
10	*Class*	*Yes*

The answers from learners were mainly choruses, and they were not given opportunities to connect the concepts themselves. The teacher was asked why he did not diversify his connections to other lessons separated by weeks or months? Mr Zulu was of the opinion that learners usually got confused when referred to different topics across the curriculum and was sceptical of this teaching approach as he thought learners would develop misconceptions. He believed that the concepts are built upon previous immediate lessons to avoid confusing the learners. Figure 5.12 below illustrates Mr Zulu’s conceptual network for the three lessons.

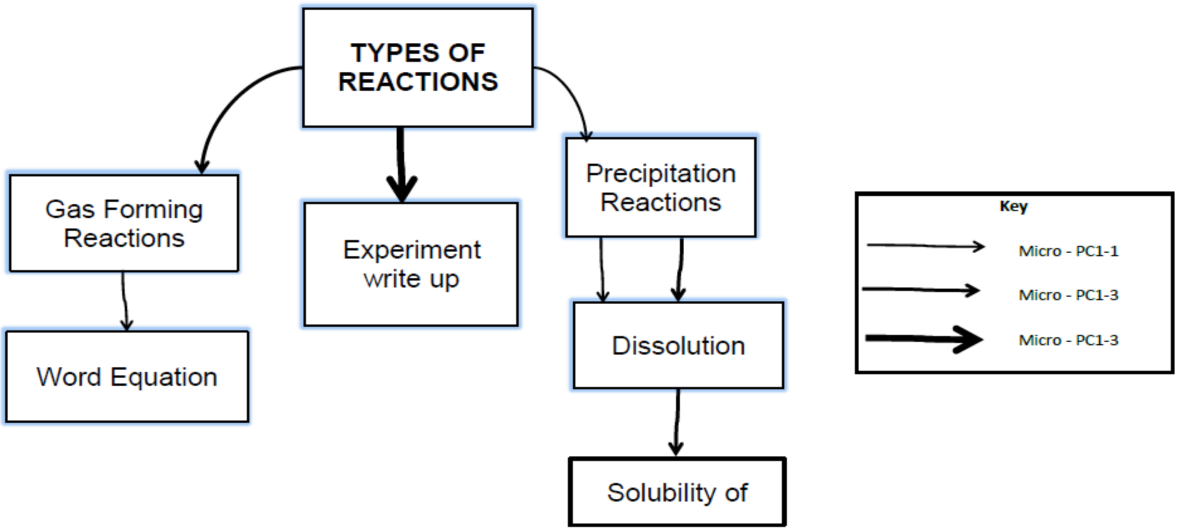


Figure 5.10: Conceptual network deduced from Zulu's Grade 10 third lesson

The only macro scale link-making that Mr Zulu made was when he reminded learners of the structure of the experiment write-up, which was covered in term 1. The micro scale was limited in the lessons observed. Mr Zulu maintained this type of teaching across the three lessons. Mr Zulu was the one making the links, and, in most cases, learners were called upon to agree with his sentiments.

5.3.2 Grade 11 Lesson 3 Analysis

Mrs Ndebele and Mrs Meyer taught Grade 11 Physical Science at a township school and a former group C, respectively. Both schools had Physical Science laboratories though were poorly stocked with material and equipment. Mrs Ndebele's school was under the program of the Gauteng Department of Education where several schools were converted into paperless schools. Although this program was enrolled in Grade 12 classes, the Grade 11 learners were privileged to use the paperless classrooms with smartboards as the matriculants were writing the preliminary examinations. Mrs Meyer's classroom had a laptop, an interactive whiteboard and a projector, which had the same functions as the Smartboard. Both Teachers were observed teaching Redox Reactions under Chemical Change; the third lesson was on the processes of oxidation and reduction and 67 links to promote continuity was made between the two teachers.

As depicted in Figure 5.8 and Table 5.3 above, micro scale linking was noticeable in the Grade 11 classes than in both Grade 10 and Grade 12 classes. The Grade 11 teachers used a lot of flip backs to earlier concepts to remind learners of the main points of the lesson. As deduced from Table 5.3, the familiar concepts used by both Grade 11 teachers on the micro scale were redox reactions, reducing/oxidising agents, balancing of equations, electron transfer, and oxidation processes/reactions. These were the central concepts, which are essential to understanding redox reactions. Both teachers and learners also did the links, but the teacher did most of the links and connections.

Mrs Ndebele made 28 links (PC1-1 = 8; PC1-2 = 11: PC1-3 = 9) compared to Mrs Meyer who made 39 links (PC1-1 = 19; PC1-2 = 12: PC1-3 = 8). Mrs Meyer made the highest number of links on the micro scale, whereas Mrs Ndebele made more links to the meso scale. However, the meso scale and macro scale links of the two teachers were comparable with just a difference of 1 link each. The major difference was in the micro scale where Mrs Meyer made more than double the links made by Mrs Ndebele. Each scale of link-making will now be examined in detail to show and compare how each teacher made connections on lessons separated by days, weeks months or years.

Looking at the micro scale first, the two teachers mainly used the micro scale links to remind learners of the central concepts under discussion during the lesson. Especially, during group discussions when learners were struggling to solve class work problems. Mrs Ndebele referred to five concepts compared to nine concepts quoted by Mrs Meyer, the rest of link-making to get to eight and 19 links, respectively, were reiterations. All concepts were relevant to the topic of redox reactions and identification of reducing and oxidising agents. Mrs Meyer managed to refer to an array of different topics and many micro links during her first half of the lesson when she did the transmission method. Her style of teaching was the same as discussed above in her first lesson.

The second link-making to promote continuity of the scientific story separated by lessons or days was comparable between the two teachers. The significant difference was in the number of concepts linked; Mrs Meyer's ten linked concepts were double to that made by Mrs Ndebele. Out of 11 links made by Mrs Ndebele, five links were a repetition of different rules to assign oxidation numbers. These were referred to during the revision of the homework given to learners on calculating oxidation numbers of elements in a compound.

In contrast, Mrs Meyer offered different connections with diverse concepts only repeating decomposition of reactions three times out of the 12 links she made. The other noteworthy difference was that most concepts linked by Mrs Meyer were from the second lesson except for the concepts of the number line and oxidation numbers that were drawn from the first lesson. Mrs Ndebele's meso scale connections were from both the first and second lessons, that is, two and three concepts, respectively. Despite Mrs Ndebele having few connections, they were balanced between the two lessons to develop the entire scientific story of redox reactions.

The last link-making, the macro scale, which connects concepts separated by months or years was comparable among the Grade 11 teachers. Mrs Meyer's macro scale reference was mainly drawn from Grade 9, and no concepts from Grade 11 first term topics were referred to. Six out of eight were Grade 9 concepts drawn from experiments of testing of gases and metals, only three connections referred to Grade 10 concepts, which were types of reactions and precipitation reactions. Such kind of connection poses a challenge of creating a knowledge gap and insinuating the fact that the syllabus is conceptually incoherent.

On the other hand, Mrs Ndebele's distribution of concepts across the grades was uniform, and she even discussed Grade 12 concepts. The Balancing of equations was a topic that was covered in Grade 10 lessons. Chemical bonding, electronegativity and half-reactions were topics drawn from Grade 11 topics, and only the concept of metal oxide was the one taken from Grade 9 topics. Learners were also alerted to the fact that redox reactions are a prerequisite of understanding standard electrode potentials to be done in Grade 12. This kind of networking concepts would develop a true scientific story of a topic and would cause learners to appreciate the interrelatedness of science concepts. The involvement of learners in making these networks is quite imperative, and it is important to analyse how learners were involved in making these connections.

Both teachers used the same methods in delivering their lessons, which were; group discussions, practical demonstrations, video animations, teacher talk and question & answer. Although the methods used were the same, their executions were very different.

Mrs Ndebele started her lessons with questions and answers, as she discussed learner homework and checking if it was done. A recap of the previous lesson's essential concepts was used to introduce the topic of the day through teacher talk, which was rich with interlinking concepts. After the teacher introduced new concepts, learners were engaged through group discussion, where their understanding of the concept was put under scrutiny. Either the animated videos or learners were used to consolidate both teachers talk and group discussion as a summary of the lesson.

In contrast, Mrs Meyer would start the lesson by writing homework answers on the whiteboard for learners to mark on their own. Thereafter, she would summarise through teacher talk the main points of the previous lesson, and in the process, she was making links herself. The teacher would introduce the new concepts either through teacher talk or an animated video. She would explain everything about the lesson by identifying links and connecting them herself. Learners would be listening and taking down notes or writing given results from a practical demonstration. The teacher talk was usually half of the duration of the lesson, and the other half will be used for group discussions. In the second segment of the lesson, learners were given class work for discussion in groups, and the teacher moved around guiding learners. Below are excerpts denoting differences of the two teachers in how they introduced the third lesson.

Turn	*Speaker*	*Transcription*
10	*Ndebele*	*………. Is there anyone who still remembers what we say reduction is? Yes Maza*
11	*Maza*	*Reduction is the gain of electrons*
12	*Ndebele*	*Yes, reduction is the gain of electrons….. So, what is oxidation? Tumi*
13	*Tumi*	*It is the loss of electrons*
14	*Ndebele*	*Yes, when we are looking at oxidation, we are looking at what, the loss of electrons, …… What is oxidation, it is gain of electrons. …….Remember in grade 10. We said that when an atom loses electrons, it becomes what?*
15	*Mable*	*It becomes more positive*
16	*Ndebele*	*I want us to have that concept what we learnt at Grade 10 look now we are applying it in grade 11. And when it gains electrons what happens to it*
17	*Lazi*	*It has more negatively…*
18	*Ndebele*	*It becomes more negatively charged fine, …*

Mrs Ndebele would identify possible links to previous lessons and asked learners to complete the links. In turn 10, the teacher asked the learners: "Is there anyone who still remembers what we say reduction is? Yes, Maza?" Maza went on to answer the question correctly in turn 11. The teacher identifies the area where links must be made but let the learners make the concept connections. This style or method is depicted in turns 14 & 15 as well as turns 16 & 17. On the other hand, Mrs Meyer introduces her lesson like a pilot telling his passengers that they must fasten their belts seat back and enjoy the flight.

Turn	*Speaker*	*Transcription*
1	*Meyer*	*You guys can take a seat and open your books for me, please. All right now, are you ready? All right good morning everybody*
2	*Class*	*Morning ma'am*
3	*Meyer*	*….By now redox reactions are not scary any more it is something flying to me. What is it? What is a redox reaction and what happens during a redox reaction? Who thinks they can tell me what happens during a redox reaction? Electrons are conserved that is the definition of a redox reaction. There must be an electron transfer; you guys can still remember the two processes reduction and oxidation ok. Now if you remember that the lion roars you will be able to remember which one loses an electron and which one is gaining that electron. All right, what I want us to look at today is in your textbook, you are going to open for me page 254. We are going to look at the classification of redox reactions now it is very important that you can understand. three types of redox reactions can take place, yesterday when I experimented on you, we were looking at the decomposition reaction. We looked a very complex molecule; copper chloride, and we broke it into more simple*

substances just copper and just chloride…....

In Turn 3, Mrs Meyer asked learners to define redox reactions, without pausing, or giving learners a chance to answer the question and she went on to answer the question herself without engaging the learners. In Turn 3, sentence ten she identifies possible links to be made by learners, about the type of redox reaction depicted in the experiment done the previous day. Instead of getting the answers from the learners so that they can link the previous lesson's concept, Mrs Meyer went on to answer the question herself. Mrs Meyer's teaching style was the same across the two grades she was teaching both Grade 11 and 12 at school E. However, in the second segment of Mrs Meyer's lesson, the group discussion phase, learners were able to identify their links and could make connections with a concept made in previous lessons.

5.3.3 Grade 12 Lesson 3 Analysis

Mr Masutha's school was a former Group C just like Mrs Meyer's school. The setup of their laboratory classes was the same with eight long benches four on each side of the classes were learners would seat while doing theory lessons. At the back of the class were eight more benches (half the size of the long benches), where practical work or experiments would be done. Mr Masutha's class was equipped with a projector and a screen but not a whiteboard as was in Mrs Meyer. All the writing was done on a green board using chalks.

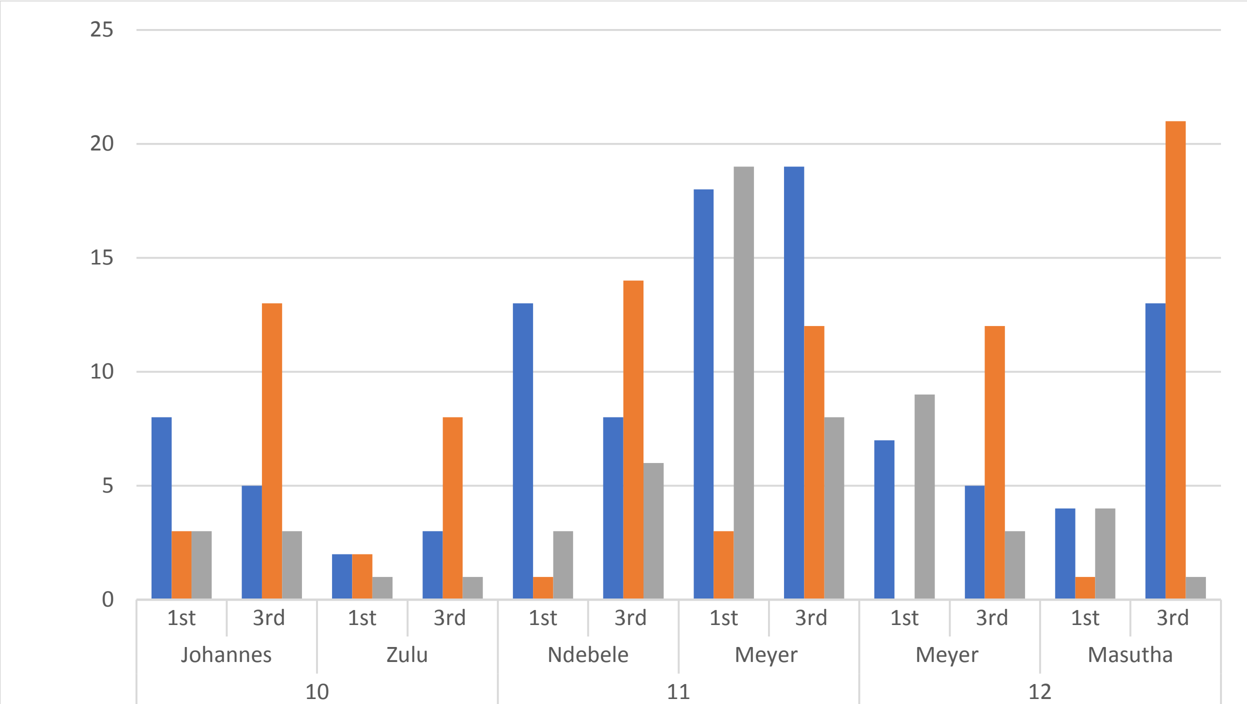
The topic of the lesson was on industrial applications of electrolysis where three different kinds of electrolytic cells were discussed, namely, membrane cell, purification of copper and electroplating. Mr Masutha did two experiments of purification of copper and electroplating. In linking the lesson with other concepts, these Grade 12 teachers were second in making the links after the Grade 11 teachers, as shown in Figure 5-8 above. Mr Masutha managed 35 links (PC1-1 = 13; PC1-2 = 21: PC1-3 = 1) and had more links than Mrs Meyer who scored a total of 20 links (PC1-1 = 5; PC1-2 = 12: PC1-3 = 3).

In the micro scale link-making, Mr Masutha had thirteen links compared to Mrs Meyer's five links. Mr Masutha's links were more on the reactions within the electrolytic cells whereas Mrs Meyer's micro links were on the uses of the products of electrolysis, especially the membrane cell. The teachers also made most of the links as in the other grades. Mr Masutha had more links in the meso scale than his Grade 12 counterpart, where he linked concepts from lesson one and 2, again with an emphasis on the reactions happening at the anode and cathode in the electrolytic cell. Similarly, Mrs Meyer, though she had few meso links, she did emphasise the reactions at the anode and cathode. Surprisingly, both teachers did not have macro link-making from the concept of redox reactions covered in Grade 11 work. Mrs Meyer had macro links in fertilisers, hydrogenation and chemistry of hair centred only on the uses of the products and not on core concepts of redox reactions, which were covered in detail in Grade 11. Mr Masutha had only one macro link made from Grade 10 topic of dissolving salts in water. Unlike in the first lesson where the concepts were constructed from topics in previous grades, the lesson on the application of electrolysis had no significant macro links. This because it is a new concept all together that was covered only in grade 12.

Mrs Meyer continued with her teaching style of first narrating the conceptual story of the lesson and then give learners problem-solving questions that will make them discuss at the last half of the lesson. In contrast, Mr Masutha discussed the concepts with the learners through the question and answer method and carried out experimental demonstrations with the help of his learners. In Mr Masutha's class, it was not only the teacher who was experimenting; instead, the teacher would select learners who demonstrated while the rest of the learners were observing. The networking of the concepts was not different from what was portrayed from the first lessons of both teachers in Grade 12. Each participating teacher maintained his way of teaching in all three lessons observed. Now, I endeavour to make a comparison of the link-makings between the teachers' first lessons and the third lessons.

Figure 5.23 below is a graphical model of representation on comparing the links made by each teacher in the two lessons. Generally, in all the lessons macro scale link-making had low-frequency scores, except for Mrs Meyer and Mrs Ndebele who had a high-frequency score of macro scale in both lesson one and 3. The inferences for this anomaly will be too general as only two teachers have been observed teaching in the grade. However, it can be noted that redox reactions are a broad topic with some connecting concepts and topics across the chemistry board of knowledge.

The topics which the teachers referred to such as electronegativity, bonding, the periodic table, types of reactions all under chemical bonding, are relevant to the topic of redox reactions. Furthermore, the topic connects with Grade 12 concepts of electrochemistry of electrolytic and galvanic cells that Mrs Ndebele correctly linked. It is my opinion from this data that the covering of oxidation numbers and redox reactions at Grade 11 is too broad a topic that needs to be streamlined.



	10				11				12			
	Johannes		Zulu		Ndebele		Meyer		Meyer		Masutha	
	1st	3rd	1st	3rd	1st	3rd	1st	3rd	1st	3rd	1st	3rd
PC1-1	8	5	2	3	13	8	18	19	7	5	4	13
PC1-2	3	13	2	8	1	14	3	12	0	12	1	21
PC1-3	3	3	1	1	3	6	19	8	9	3	4	1

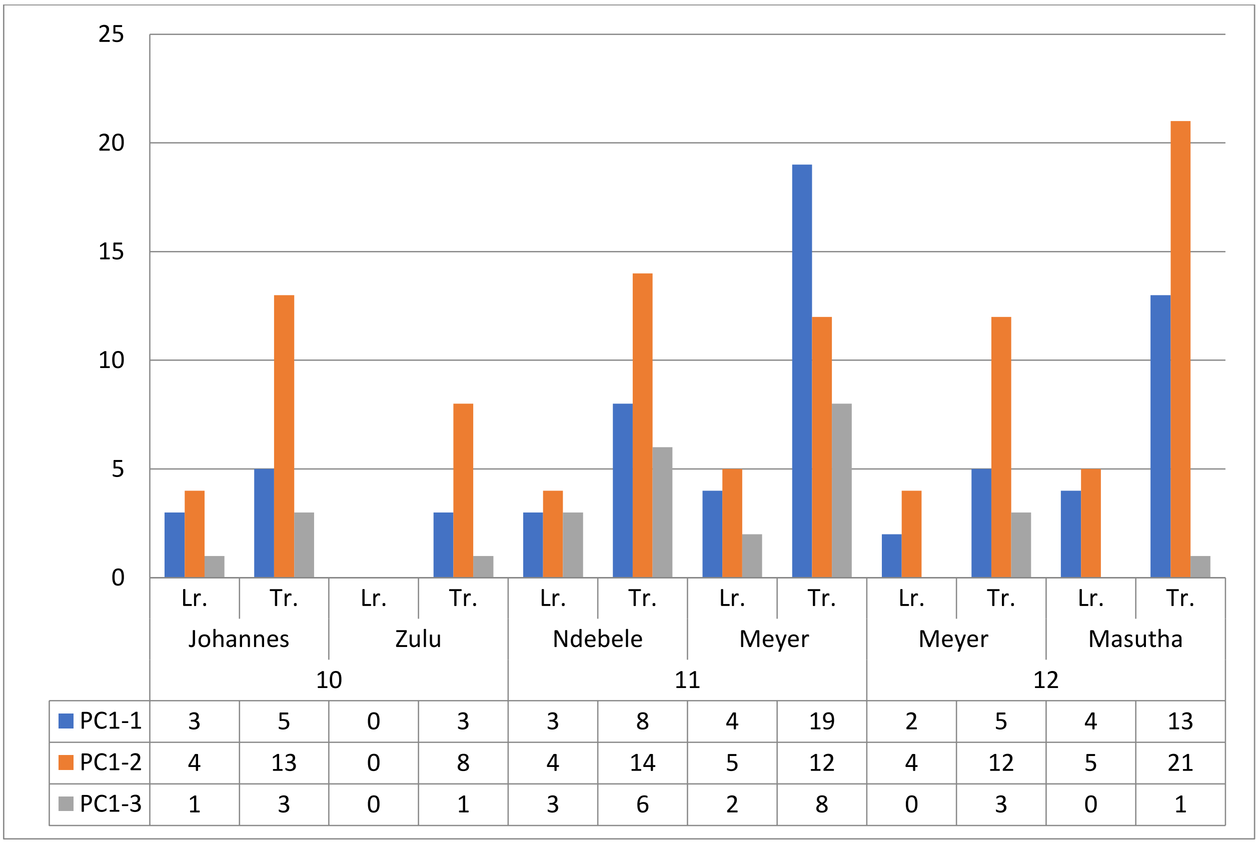
Figure 5.11: Lesson 1 & 3 comparisons of link-makings

Considering that the concept of oxidation numbers is not covered in Grade 10. It will be prudent to realign the content document by bringing the oxidation numbers to Grade 10 and relieve the concept of congestion in the Grade 11 topic of redox reactions. Besides the Grade 11 macro scale anomaly according to the data gathered in this research, the micro and meso scale generally increased from lesson one to lesson 3. Although, the link-making is a skill or approach that depends on the prowess of the teacher. The accumulation of concepts and their connectedness is an indication that the curriculum is coherently aligned except for concepts of oxidation numbers and electrolytes that are missing in Grade 10 and 11 respectively. Hence, the Grade 10 and 11's content coverage should be streamlined in accordance with the proposal above.

The main focus of the above analysis was to investigate the nature of links made by teachers in each lesson as displayed in Figures 5.11 for lessons 1 and 3. It is of interest to compare how many links were done by the learners versus those done by their teachers, especially in lesson 3 where most parties made some links. Learner links were only tallied during class discussions with the teacher.

5.3.4 Teacher Vs Learner Link-Making

The link-making made in each lesson was scrutinised to ascertain how many links were made between teachers and learners, as shown in Figure 5.12 below.



Grade	10				11				12			
Teacher	Johannes		Zulu		Ndebele		Meyer		Meyer		Masutha	
	Lr.	Tr.	Lr.	Tr.	Lr.	Tr.	Lr.	Tr.	Lr.	Tr.	Lr.	Tr.
PC1-1	3	5	0	3	3	8	4	19	2	5	4	13
PC1-2	4	13	0	8	4	14	5	12	4	12	5	21
PC1-3	1	3	0	1	3	6	2	8	0	3	0	1

Figure 5.12: Comparison of links made by teachers and students lesson 3

The diagram above shows a clear visual analytical view and comparison of the distribution of links between teachers and their learners in lesson 3. It is shown that in all the six classes and across all the three grades teachers made more links than learners. However, in Mr Zulu's class, no learner in the third lesson made any conceptual connections; this is because of his transmission style of teaching. Generally, the higher the teacher's links, the more learners also made links. All teachers made more meso scale links than any other link scale in the third lesson, as well as the learners. Learners made more links in classes where there was learner engagement (Johannes, Ndebele, Meyer and Masutha). The nature of engagement also determined the number of links made by learners. The more the learners were engaged, the more they made the links and teachers who had group discussions, their learners made more links as well (Johannes's learners = 4; Ndebele's learners = 4 and Meyer's learners in Grade 11 = 11). However, Mr Masutha had no group work done in his classes, but he engaged learners through question and answer. His learners also scored highly on micro and meso scales. Remarkably, there was no macro link-making made by teachers in Grade 12 classes. Consequently there were no macro links made by learners as well.

5.4 Discussion of results

Generally, the macro scale was the least linked scale across all teachers in all grades. However, the first lesson should have a significant connection with other preceding topics that have a link with the topic that is being discussed at hand. There are a couple of observations that can be made in connection with the five cases understudied here. Firstly, when comparing teachers in the same grade, they do make a significant number of links from the previous topics linked to the topic at hand. The links made can be categorised into extent and depth of link-making. Where the extent of link-making refers to the number of connected concepts the teacher facilitated in the process of teaching and learning. Consider Table 5.3, above where Mr Johannes had three conceptual macro scale links from three different topics done in the first term, compared to Mr Zulu's one macro scale link with one topic done in the first term as well. Therefore, Mr Johannes had more extensive conceptual cross-links than Mr Zulu.

Whereas, the depth of link-making for both teachers was only limited to mentioning in passing that learners had an encounter with the concept of chemical bonding in the first term. There was no conversation about what was deliberated on chemical bonding in the first term, and how it was related to the concept of dissociation, which was under discussion.

The depth of link-making refers to the discussions that emanated from the connections, and the manner of discourse the teacher allowed around the concept. Although Mrs Meyer had a high-frequency score of macro link-making, it was the depth of the connections that were questionable. The teacher did most of those links without discussing them with the learners. Among all the teachers, it was only Mr Masutha, who had significant in-depth discussions of what the learners understood about how conduction of electricity took place in the electrolytic cell.

Secondly, the curriculum should be sequenced in such a way that it should be easy for learners and teachers to connect related concepts with easy. That is, the sequential arrangement of topics should be hierarchical and coherent across the grade, and within the grade (Department of Education, 2011). However, what we found out in chapter 4 was the opposite more so within the grade, where physics topics separated otherwise coherent chemistry topics. Hence in the first lesson, I barely saw teachers making meso links (linking concepts separated by days and weeks) because there was no linking topic. In this case, teachers had no control over the sequential arrangement of topics within the grade. It is the prerogative duty of the Department of Basic Education to publish the work schedule that has been derived from the content document.

Since the beginning of CAPS in 2014, the work schedule had only been changed in January 2018. The re-arrangement of topics made was done to give other topics an opportunity to be done earlier and always on the last days before the examinations. However, the topic of electrochemistry where this project is centred on has remained unchanged, and the topic of Alternating Current that precedes it has not changed as well.

Micro scale link-making was mainly covered extensively and in-depth by the majority of the teachers, except for Mr Zulu who scored a frequency of two micro scale link-makings. In most of the classes, we saw that the learners were fully participatory and engaged in meaningful discussions whenever the teachers gave them the opportunity to do so, especially in the last lessons. Learners had prior knowledge of the concepts from first and second lessons and could quickly make connections. The meso scale was prevalent during class, and or group discussions. Hence, my argument that the focus should be on the social constructivist approach that impedes social interactions and peer support simultaneously (Cullen, 2015).

The continued alternation of Chemistry and Physics topics in the work schedule which has to be servantly followed by the teachers compromises the building of the development of the scientific story and consequently compromises meaningful learning of science. The primary goal of meaningful learning is to help learners make interlinking connections between concepts to develop the scientific story (Krajcik et al., 2014). Failure to expose learners to such an in-depth discussion ignores learners' previous knowledge. Once, the learners' previous knowledge is not taken into perspective during the introductory part of a topic; the concept will remain a standalone fact in the mind of the learners. Discrete concepts are difficult to comprehend as they do not have a foundation of prior concepts on which they should be built upon. Fortus et al. (2015) argue that the acquisition of scientific knowledge is more meaningful when it goes beyond the accrual of discrete facts and concepts.

Conceptual understanding is achieved when science learning focuses on assisting learners to develop commanding explanatory ideas that are fruitful across various contexts. However, in this study, there an accumulation of discrete facts and concepts through class discussions, and these do not help learners to comprehend the intended scientific story conceptually. Furthermore, Cullen (2015) argues that the curriculum must be carefully sequenced for learners to be able to meaningful concept networks for learners to build a broad and interconnected body of scientific knowledge. Hence, it is imperative for the department of primary education to re-consider the arrangement of the topics in the annual teaching plan, or two split the Physical Sciences into two separate subjects of Physics and Chemistry.

5.5 Conclusion

This chapter analysed the prompts of research question 2, which investigated the extent to which five teachers' practices fostered the development of a scientific story. The teachers were teaching electrolytic cells in their natural settings (the schools). I tried by all means not to control any variables during the investigation. The pedagogical link-making was used as the analytical tool to evaluate each participants' practice if it supported the meaningful creation of scientific knowledge and developing an understandable scientific storyline.

Four findings emanated from the study of this second research question. Firstly, it was found out that generally the arrangement of the topics across grades in the FET phase are coherent and progressional and support the facets of a spiral curriculum. However, there are significant omissions of essential concepts in Grade 10 and 11, which puncture black holes into a curriculum that was supposed to be coherent, hierarchically and logically arranged body of scientific knowledge. The two omitted concepts were oxidation numbers in Grade 10 and the notion of electrolytes in both Grade 10 and 11. It was then discussed that there was a need for the inclusion of these said topics in the suggested grades. Secondly, the macro scale was less utilised by most of the teachers except for Mrs Meyer and Mrs Ndebele. The failure by teachers to link concepts on a macro scale meant that previous learner knowledge was insignificantly utilised in the building of the scientific story of Electrolytic cells.

The third finding had to do with the inadequate use of meso linking indicators in all first lessons of each teacher across all grades. However, the use of the meso scale increased significantly in the third and concluding lesson. Last but not least, it was discovered that when interrelated topics are grouped and presented to learners coherently, there is increased use of micro scale link-making. Hence, teachers and learners were able to link concepts within the lessons and between consecutive lessons within a grade.

The next chapter deals with research question 3, which addresses the construction of knowledge during the teaching of scientific concepts. Five out of six pedagogical approaches of link-making to support knowledge building would be under consideration. However, due to the broadness of these approaches, they are grouped into two separate categories, which are the relevance of scientific concepts to the everyday life of learners (chapter 7) and use of multimodalities and multilevel of thought (chapter 8).

CHAPTER 6

The relevance of scientific concepts to everyday life and real-world phenomena

6.0 Introduction

The preceding Chapter dealt with how teachers promoted the continuity of the scientific story in the teaching of fundamental concepts of electrolytic cells from Grades 10 to 12. It was found that the macro scale was less utilised than the meso and the micro scales. The meso scale was less used only in the first lesson but in the second and last lessons, its use by teachers gradually increased. In contrast to the meso and macro scales, the micro scale was prominent in all the observed lessons.

As a result, the promotion of continuity to develop a scientific story was compromised on the macro scale. This chapter focuses on how teaching supported knowledge building in the learning of the electrolytic cells and its important concepts at the senior secondary level. The chapter answers the third research question: “To what extent do teachers use knowledge building strategies in the teaching of electrolytic cells and its underlining concepts at the senior secondary level?”

6.1 Pedagogical link-making to promote knowledge building

Pedagogical link-making to support knowledge building has six approaches (Scott et al., 2011). Each of the six approaches has one or more pedagogical tools that are used to support its implementation. The approaches, and the coding system I developed to identify each pedagogical tool are displayed in Table 6.1 below.

Table 6.1: Coding system in pedagogical link-making to support knowledge building

PM L Form	Scott, Mortimer, & Ametller Approaches’ approaches	Scott, Mortimer, & Ametller Approaches’ Pedagogical tool	My Codes
Link-making to promote knowledge building	Making links between every day and scientific ways of explaining (KB1)	Integration	KB1-1
		Differentiation	KB1-2
	Making links between scientific concepts (KB2)	Linking scientific concepts	KB2
	Making links between scientific explanations and real-world phenomena (KB3)	Simple phenomena	KB3-1
		Complex phenomena	KB3-2
	Making links between different scales & levels of explanation (KB4)	Micro	KB4-1
		Macro	KB4-2
		Symbolic	KB4-3
		Pictorial	KB5-1
		Diagrammatic	KB5-2
		Chemical equations	KB5-3

	Making links between modes of representation (KB5)	Mathematical expressions	KB5-4
		Videos	KB5-5
		Tables	KB5-6
		Models	KB5-7
		Graphical	KB5-8
	Making links between analogous cases (KB6)	Analogies	KB6

The letters KB represent the pedagogical link-making to support Knowledge Building, the first number represents the approach, and the number after the hyphen stands for the pedagogical tool. For example, KB1-1 represents pedagogical link-making to support knowledge building approach 1-1: Making links between every day and scientific ways of explaining where integration is the pedagogical tool.

My analysis of link-making to support knowledge building took a different approach from my analysis of link-making to promote continuity. In this case, all lessons have been taken into consideration instead of the first and last lessons as done in Chapter 5. A total of 18 lessons were analysed.

There were three lessons per teacher per grade (Grade 10, 11 & 12). Each transcribed lesson was examined according to the coding in Table 6.1. In the previous chapter, the focus was on two lessons: the first and the last lessons. The first lesson looked at how the teacher ushered learners into a new topic through linking it with previous concepts and other bodies of knowledge related to those concepts. The last lesson concentrated mainly on how teachers consolidated the interlinking ideas of the new topic and how they are linked with other concepts in future learning. In contrast, the pedagogical link-making to support knowledge building looks at approaches that lead to learner comprehension of concepts using links made during the explanations of the scientific phenomenon. Hence, it is essential to look at all the lessons and understand how the teachers managed or how they missed opportunities to make the scientific concepts explicit and understandable to learners.

The six pedagogical approaches for supporting knowledge building are: making links between everyday and scientific ways of explaining; scientific concepts; scientific explanations and real-world phenomena; modes of representation; different scales/levels; and analogous cases. The descriptions and examples of each of the approaches are detailed in Chapter 2. Each approach is briefly summarised to remind the reader of the gist of each link-making as it is analysed. The reader is reminded that central to the notion of knowledge building is the fact that knowledge is a product of social interaction created by learners in the classroom community (Zhao & Chan, 2014).

Pedagogical link-making to support knowledge building requires the creation of conceptual networks between various forms of knowledge to help learners in developing a meaningful understanding of scientific concepts (Scott et al., 2011). Therefore, to foster conceptual understanding teachers are expected to engage the six pedagogical approaches in their practice to ensure meaningful learning of the subject matter. Figure 6.1 below shows a summary of the total number of links made by all observed teachers for all six approaches of pedagogical link-making to support knowledge building.

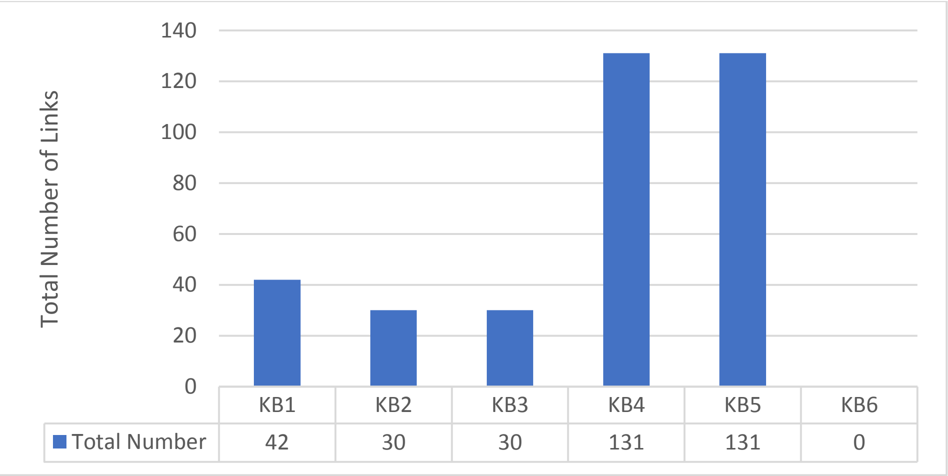


Figure 6.1: Total number of links observed for each Knowledge building approach by the five teachers

As shown in Figure 6.1, link-making between different scales and levels of explanation (KB4) and link-making between modes of representation (KB5) had very high scores of links or connections made by all five teachers in a total of 18 lessons observed. Linking-making between every day and scientific ways of explaining (KB1) was three times than KB4 and KB5 approaches with 42 connections among all the teaching in the same number of lessons observed.

Making links between scientific concepts (KB2) and link-making between scientific explanations and real-world phenomena (KB3) had a similar number of links but were almost four times less than the two approaches with highest scores of link-making. Link-making between analogous cases (KB6) was not observed in any one of the lessons presented by the participants. In this chapter and Chapter 7, each of the five approaches is analysed to ascertain how these link-makings supported knowledge building of the topic electrolytic cells and its key concepts.

In this study, the six pedagogical approaches are divided into two categories. The first refers to how scientific concepts can be related to every day and real-world phenomena. The second refers to the use of multiple modalities and scales of explanation in the teaching of scientific concepts. The relationship of scientific concepts to everyday and real-world phenomena consists of the first three pedagogical approaches, namely, links between everyday and scientific ways of explaining, scientific concepts and scientific explanations and real-world phenomena. The multiple modalities and different scales and levels of explanation category include the remaining three link-making approaches which are modes of representation, different scales/levels as well as analogous cases. Although the first three approaches are discrete and independent, they tend to converge on the way scientific concepts should be explained to foster meaningful learning for the learner. The approach for link-making between everyday and scientific ways of explaining is first to be analysed.

6.2 Approach 1: making links between everyday and scientific ways of explaining

As described in Chapter 2, this approach has two sub-approaches: links to integrate, and links to differentiate between scientific and every day ways of explaining. The link to integrate speaks to a situation where the scientific term or concept has the overlapping meaning with the everyday way of explaining, and the role of the teacher is to reinforce the explanation (Scott et al., 2011). Where there is a difference between scientific and everyday ways of explaining, learners should be made aware of the differences. Consequently, the teacher is expected to address the links to integrate, and the links to differentiate between scientific and every day ways of explaining for learners' conceptual understanding. Table 6.2 gives a summary of observed lessons and how the teachers used the first approach of linking scientific and everyday ways of explaining. Please note that KB1-1 refers to links to integrate and KB1-2 links to differentiate between scientific and every day means of explanations.

Table 6.2: Making links between everyday and scientific ways of explaining

Teacher	Grade	KB1-1 (Links to integrate)	No. of Links	KB1-2 Links to differentiate	No. of Links	Total No. of Links
Johannes	10	Dissolution	3	Solution	2	5
		Precipitation		Dissolve		
		Synthesis				
Zulu	10	Precipitation	3	Dissolve	2	5
		Dissociation		Precipitate		
		Synthesis				
Ndebele	11	Cell	4	Charge	2	6
		Battery				
		Reversible		Neutral		
		Simultaneous				
Meyer	11	Current	5	Species	4	9
		Nucleus		Charge		
		Rusting		Displacement		
		Decomposition		Synthesis		
		Battery water				
Meyer	12	Spectator ion	7	Agent	4	11
		Cell		Energy		
		Battery		Species		
		Rusting		Decomposition		
		Saltwater				

		Balancing Equations current				
Masutha	12	Current Salt	2	Decomposition Melting Dissolving Impurities	4	6

Table 6.2 above shows how each teacher used the two opposing link-making strategies to explain different scientific concepts. The linking word was placed either on integration (KB1-1) or differentiation (KB1-2) depending on how the teacher used the word in the lesson. The table above also shows the total number of links per approach in the three lessons observed for each teacher. To give a more precise representation of how each teacher used the words a graph of links per category (KB1-1 and KB1-2) was plotted (see Figure 6.1 below).

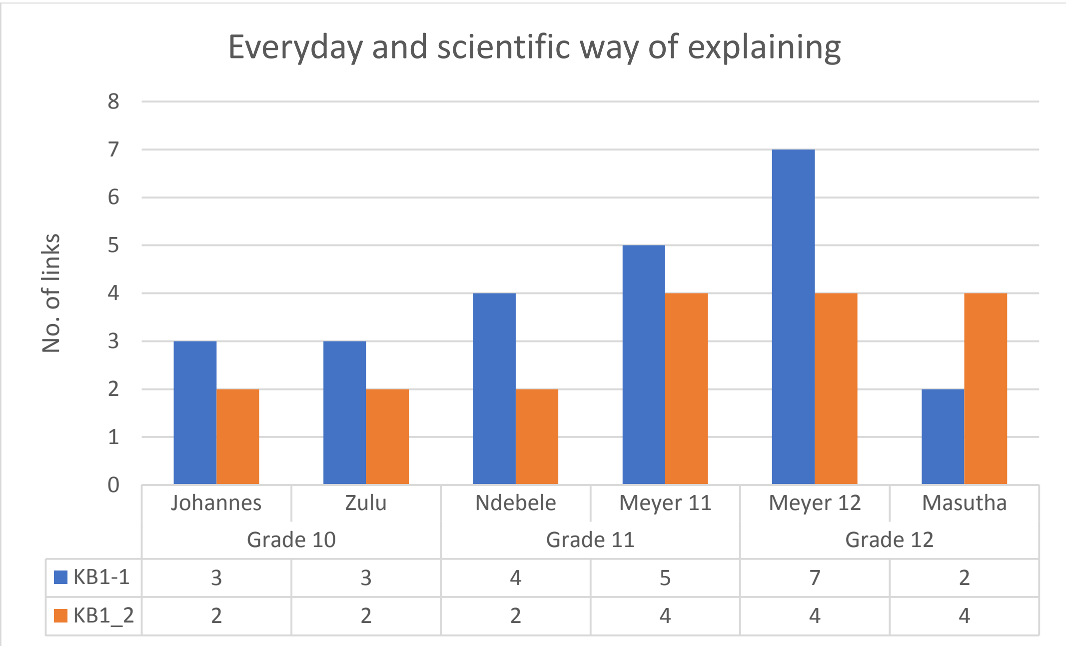


Figure 6.2: Comparison of the use of KB1-1 and KB1-2 link-makings Everyday and scientific way of explaining

From the graph above, it seems that teachers seldom used the approach to differentiate scientific words or concepts from everyday words (KB2-1). This was true of all teachers and in all grades except for Mr Masutha who used more links to distinguish everyday words from scientific words than links to integrate. The rest of the teachers who were observed used more connections that integrated concepts than the links that differentiated between scientific and everyday explanations.

Looking at individual teachers, it is clear from Figure 6.2 that Mrs Meyer had the highest number of links overall particularly in integrating everyday ways of explaining and scientific ways of explaining scientific concepts. She made more links than each of the teachers that she shared a grade with. For instance, in Grade 12, Mr Masutha made two links while Mrs Meyer made 7. At Grade 11, Mrs Ndebele made four integrating links while Mrs Meyer made 5. The Grade 10 teachers seemed to make a similar number of connections. There is evidence from the above analysis that the integration of everyday and scientific ways of explaining increased across the grades. This could be a result of an increase in the relevance of the concepts to societal processes and industrial processes across the grades.

6.2.1 Link-making to integrate everyday and scientific views

Mr Johannes used three link-makings of integration namely dissolution, dissolving and synthesis. Although these words are rarely used on daily bases, Mr Johannes explained to learners the meanings of these words and their possible use in everyday life on different occasions.

Johannes: If you have been reading literature books or novels you might have come across the word dissolution and, in such context, it means separation into different parts. That has the same meaning in science where NaCl the solute is separated into its ions that are cation sodium ion and anion chloride ion. So, dissolution is the process where the solute separates into ions or molecules, and molecules of a solvent surround each ion or molecule, and our solvent is water. So, the anion and cation of sodium chloride will be surrounded by water molecules.

The extract above was drawn from the first lesson when the class was discussing the dissolution of solutes in a solvent such as water. The teacher integrated the everyday meaning of the word dissolution with its scientific meaning. However, the integration could not be entirely attributed to meaningful learning as the learners were not given a chance to engage with the word to ascertain their understanding of the everyday meaning of the word dissolution. The teacher is the one who was familiar with the meaning, most probably due to his depth vocabulary as I noted that was the trend in all the three lessons Mr Johannes was observed teaching. Nevertheless, in some instances, the teacher engaged learners in finding the meaning of specific words such as precipitation.

At the beginning of the second lesson, Mr Johannes involved learners in the discussion of the meaning of precipitation (see the excerpt below).

Turn	*Speaker*	*Translation*
15	*Johannes*	*Yesterday when I was giving you the type of reactions, I think I did define what precipitate reaction is. But let me just add on to that. In Geography we know that there is precipitation when we look at the water cycle, are we together?*
16	*Class*	*Yes*
17	*Johannes*	*When you look at the water cycle, we have water falling as what?*
18	*Lerato*	*Solid*
19	*David*	*Snow*
20	*Johannes*	*They fall as what?*
21	*Class*	*Snow*
22	*Johannes*	*As snow ne*
23	*Class*	*Yes*
24	*Johannes*	*Very correct besides snow, they can fall as what?*
25	*Class*	*As rain*
26	*Clint*	*As hail*
27	*Johannes*	*As hail, besides that, it can fall as what?*
28	*Clint*	*As rain*
29	*Johannes*	*As rain ne. So when we talk about precipitation it is something that is coming from somewhere, now from the water cycle, it is water falling from the sky. But when we are looking from a chemical reaction, precipitation is the falling of a solid out of a solution. The falling of a solid out of what?*
30	*Class*	*Solution*
31	*Johannes*	*The solution, this occurs when you react two solutions that a clear. Remember a solution is homogeneous…...?*
32	*Class*	*Mixture*
33	*Johannes*	*The mixture is that so? So, if it becomes a heterogeneous mixture, we are now having a solid. It means it is a precipitate kind of a reaction.*

In the above passage, the teacher introduces the word precipitation from the water cycle perspective, and learners were conversant with the concept and were involved as can be learned from the extract. The teacher then linked the meaning of the word precipitation from the water cycle with a scientific explanation of precipitation reactions. The scientific explanation was constructed upon the collective knowledge of different forms of how rain precipitates from the clouds using Lemke's concepts of teaching from simple to abstract (Lemke, 2005).

Unlike, the discussion of dissolution where learners were not involved, in this case, Mr Johannes used a powerful tool of learning, learner engagement. This helps the observer to understand what the learners are going through during the process of teaching and learning. The link-making to integrate the meaning of precipitation from the two views was initiated by the teacher who then posed guiding questions that helped in integrating the geography phenomena to ways chemists explain precipitation. Hence, everyday concepts can emanate from another learning area across the school curriculum. The essence of the matter is that learners should be well versed with the explanations and can take part in the discussions with familiarity and understanding. Everyday explanations can be drawn from what learners encounter in their homes, and Mr Zulu gave such an example in the teaching of the same concept of precipitation reactions.

Mr Zulu presented an everyday situation of making tea with spoiled fresh milk, during the first lesson of a Grade 10 class. The class was discussing four factors that proved a chemical reaction had taken place. In the excerpt below, the whole class discussion was on the formation of a precipitate.

Turn	*Speaker*	*Translation*
23	*Zulu*	*So, we can talk of heat changes, either temperature increases or decreases we know that a chemical reaction has taken place. Then we have got another o**ne.*** *(Disturbance from the HOD sciences and the teachers continues after the disturbance).* *The 4th one, it is one of the most important ones …..... The formation of what?*
24	*Class*	*Formation of a precipitate.* *(Some learners could hardly pronounce the word).*
25	*Zulu*	*But let me call it a solid or precipitate. two liquids you mix together, and suddenly, a solid substance is formed inside, net? We have these reactions taking place nowadays. How do we tell that fresh milk has gone bad?*
26	*Class*	*Smell*
27	*Zulu*	*Smell yes. You buy from the shop when you come and prepare your tea, you pour it there, and there you say lobisi lubolile (this milk has gone bad). How do you tell?*
28	*Tracy*	*the way eeh, the way it looks*
29	*Zulu*	*The way it looks – yes, the way it looks*
30	*Tracy*	*Yes, the way it looks, I cannot describe it in English sir.*
31	*Zulu*	*……. how do you tell this milk is no longer fresh? Sylvia*
32	*Sylvia*	*When bad fresh milk is poured in hot water, it forms very small particles that look like some clots.*
33	*Zulu*	*Some clots. Some solid stuff is that, so that is what we call a precipitate and for us, it tells this milk is no longer right for tea….*

The teacher used relevance (which will be discussed later in this chapter) of everyday explanation to try and explain the scientific concept of precipitation. The everyday explanation from the teachers' perspective was that if hot water and milk that has gone bad (spoiled milk) were mixed, there are lumps which immediately form and that is the evidence that the milk has precipitated. The statement seems to be true, but there is a problem with the teacher's argument, which can give rise to a misconception that the milk will precipitate when it is poured in hot water. In fact, the bad smell is the evidence that milk is spoiled, and precipitation has already taken place. When the spoiled milk is placed in hot water the lumps are formed due to the coagulation of precipitated milk; it does not signify the start of precipitation. Rather precipitation of milk is a result of fermentation that lowers the pH of the mixture (milk) and causes the precipitation of neutral protein in milk (Fox, Uniacke-Lowe, McSweeney, & O'Mahony, 2015). The studies on the effect of temperature and pH have shown that precipitation of protein in milk is strongly influenced by the pH (Post, Arnold, Weiss, & Hinrichs, 2012).

Therefore, in the teacher's example, the milk would have gone bad already (spoiled), and precipitation would have taken place due to the lowering of the pH of milk by the process of fermentation. The teacher did not give the scientific view of how precipitation of pure substances takes place, the way Mr Johannes had explained to his learners. Hence, it is difficult to ascertain the conceptual understanding of this concept by learners.

In the excerpt above, Mr Zulu linked the clotting of milk which learners were familiar with, but some learners like Tracy could not describe how spoiled milk looks like. In turn 30, Tracy confesses that language is a barrier in trying to describe what she thinks happens when one makes tea with spoiled milk. The teacher did not give her a chance to describe in her language of understanding. During the interview, Mr Zulu was asked particularly on this issue why he did not give Tracy an opportunity to use her vernacular to express herself. The teacher believed that learners must be encouraged to converse in the language of instructions as they are not allowed to write examinations in vernacular. He strongly felt that learners should be strictly be compiled to speak English to avoid such mishaps in the examinations where they will be marked wrong.

In contrast, the teacher himself code-switched between Zulu and English (see turn 27), where he says “lobisi lubilile” meaning the milk is spoiled. His reaction to code-switching was that it brings a quick understanding of what the teacher is referring to and learners get to know the point of discussion. After a short discussion, he acknowledged that code-switching was necessary for conceptual understanding and not for examinations.

Code-switching is also crucial in allowing learner engagement as the barrier of language would have been eliminated. On explaining precipitation, reactions both teachers Mr Johannes and Mr Zulu managed to bring out what learners get to understand better by engaging them. Where learners were engaged in these two lessons, the discussions were productive and encouraged meaningful learning that gave rise to conversations that promoted knowledge building. Such engagements do not only encourage knowledge building but reveal learner misconceptions as was evident in Mr Masutha’s Grade 12 class of Physical Sciences.

During one of the discussions on making electrolytes Mr Masutha mentioned that copper chloride was salt, one learner was astonished and quickly pointed out that salt is always white and not blue. The teacher had to integrate this idea of everyday ways of explaining and the scientific ways explaining by mentioning that salt is not confined to sodium chloride, which is white only. Instead, it should be defined using the Grade 10 concept of acidic reactions with basis and metals. Salt and water are the products formed when acids and bases react, and the reaction between a metal and acid produces salt and hydrogen. One learner then asked about how many coloured salts there are. To which the teacher referred the class to the periodic table and on transition metals. He highlighted that almost all transition metals have different colours depending on the oxidation number of the metal. The discussion clarified the misconception that all salts are white and only NaCl is salt.

For the remainder of his class, in integrating scientific and everyday ways of explaining Mr Masutha followed the same method used by Mr Johannes when he described the dissolution of salts. This involves mentioning and explaining everyday words without engaging learners. The same trend was observed in Mrs Meyer’s and

Mrs Ndebele's classes. Although Mrs Meyer made the highest number of links than any other teacher, none of all those links was discussed with the class. Instead, she did the explanations herself and did not engage the learners in discussing the everyday explanations against the scientific ways of explaining. Similarly, Mrs Ndebele had no discussions with learners about the links made whether integration or differentiation.

When the teachers were asked why they did not give learners a chance to explain some of these everyday phenomena the way they understand. Mrs Meyer had this to say, "These everyday experiences bring about the unnecessary debate as they differ from one community to another and you start a debate that will take your time and would not finish the planned days' work". Hence, she explained everything to the learners so that they get the scientific ways of explaining from the onset. A follow-up question was asked about how she knows if learners have understood what she is teaching if there is no such engagement. To which she replied that her learners know that if they want to ask, they ask but to those who are shy they will be catered for during the discussion time. "In all my lessons I give time to learners to discuss at the end of my explanations", explained Mrs Meyer. She claimed that she moves from one group to the other sorting out issues and hearing out their arguments, at least arguments among three or four learners is manageable instead of the whole class discussion. Mrs Ndebele also shared the same sentiments as Mrs Meyer. Below is an extract of what Mrs Ndebele's interview on why she did not offer learners a chance to discuss the common understanding of words such as reversible which she used during her lesson.

Turn	*Speaker*	*Transcription*
12	*Ndebele*	*Learners bring about unnecessary explanations which are parallel to the scientific standpoint. The problem is you find that other learners will believe those parallel views and forget about the science view. To make it worse learners will write these parallel views in the examinations instead of the scientific views. Hence, I found it plausible to give them the right view from the onset.*
13	*Researcher*	*How will you ensure that they have understood*
14	*Ndebele*	*I will only know of their misconceptions once I give them homework and test. I think you have noticed that I check and discuss homework before I start my lesson. I do that because that is when I pick their misunderstanding and correct it before going on to another topic.*

The above excerpt shows that teachers are more concerned about learners passing examinations over learners conceptual understanding. Therefore, in most cases, teachers focus on completing the syllabus so that learners can write examination albeit sacrificing teaching for conceptual understanding. Hence, Potgieter and Davidowitz (2010) found out that first-year chemistry learners had a low conceptual understanding of the content taught in high school. The learners who were interviewed by these researchers confessed that they mostly memorised to pass examinations. The fear teachers have about learners not taking their scientific explanations once other views are discussed in class, is a stigma that teachers must overcome.

Contrary to the teachers' views, my observation was that learners continued to discuss their everyday views in their small group discussions during the lessons and they would reach a consensus albeit without the teacher's input. Very few groups asked the teacher on what they agreed or disagreed on. It appears class discussion on these misconceptions enhances understanding of the intended concepts

6.2.2 Link-making to differentiate everyday and scientific views

In differentiation link-making, the everyday explanation is different and contradicting the scientific explanation. The teacher should be able to distinguish between the two and help learners understand the scientific explanation. The link-making for differentiation is useful when the everyday explanation is not compatible with the scientific explanation. If the difference is not addressed, it is likely to hamper meaningful learning as the everyday meaning of the word contradicts the scientific meaning. Hence, teachers should be able to identify concepts for which everyday views are different from scientific views. As indicated in Figure 6.1, very few differentiation link-makings were discussed in the six different classrooms. Very few of them were teacher initiated. Instead, they emanated from learners when they were responding to questions. A good example was from Mr Johannes's first lesson when the class was discussing the process of dissolving. The extract below exhibits how the discussion unfolded between the teacher and the class.

Line	Speaker	Transcription
104	*Teacher*	*. .... So, guys in this beaker I am going to mix salt and water, I want someone to describe what happens to the salt. Yes Clarice*
105	*Clarice*	*It dissolves in water.*
106	*Teacher.*	*Correct and what is to dissolve we have been saying this word without explaining it.*
107	*Talent*	*The salt will disappear in the water.*
108	*Teacher*	*Ok, it disappears right, so you mean if I drink this water, I will not taste the salt.*
109	*Anna*	*The water will be salty sir, but the salt would have disappeared, and we cannot see it, but it's there because you can still taste in water.*
110	*Teacher*	*Does the word disappear the right word to use? When something disappears will you still find it there? If it is still there, but you cannot see it, we say it's invisible. Am I correct?*
111	*Class*	*Yes*
112	*Teacher*	*So, what is to dissolve.*
113	*Peter*	*Can I try it? It's breaking down into invisible particles, I think.*
114	*Anna*	*Ok, sir. I think the salt will be part of the water and forms a homogenous solution and its particle are invisible.*
115	*Teacher*	*Yes. When a solute is incorporated into a solvent to form ions which are now attracted by the water molecules. So, we can say dissolving is the process in which the solute ions and the solvent molecules interact and attract each other to form a solution.*

The first definition by Talent in turn 107 is what a layman would define the word dissolving. It is a misconception; learners have as indicated in literature that the learners commonly say salt disappears or melt in water (Adadan & Savasci, 2012). The teacher did not accept the definition and challenged learners through probing and asking questions (turns 108 and 110). Such questions make learners think and discard their prior thinking as was done by Anna in turn 114. In turn 109, she had a strong viewpoint that the salt has disappeared in the water. The teacher's probing questions challenged her standpoint, and she was eventually convinced that salt does not disappear. She then offered to redefine the term dissolving, with better wording that suggested a change of her understanding, instead of 'disappearing' she used 'part of'. That change of viewpoint signifies a change of perception, which is the goal of link-making to differentiate the scientific view and everyday view. The moment that goal is achieved then conceptual understanding has taken place through knowledge building.

It is evident that in classes where learner involvement was rampant that is where misconceptions were mined and corrected by the teachers. However, in those classes where the teacher identified possible misconceptions and addressed them herself or himself, it was difficult to know whether there were any misconceptions that prevailed in the minds of the learners. This prompted me to ask teachers if they always address everyday explanations and scientific ways of explanation on science concepts to help learner understanding. Below are excerpts of what teachers said about the question;

Researcher *Mr Johannes, do you plan to address the issues between everyday ways of explaining and scientific ways of explaining? Considering that you use unfamiliar and familiar words in everyday explanation like dissociation and precipitation, respectively.*

Johannes *Some of the word I plan some of them I do not plan, for example, dissociation which I am referring to in one of my listens. it just came when I was explaining, and I had not planned for it. However, the precipitation one I had to plan because from my experience it's quite difficult for learners to comprehend where the solid comes from.*

The rest of the teachers were asked the same question as Mr Johannes but without referring to incidences from their lessons, and they had this to say;

Zulu *Rarely do I plan for these everyday words and scientific explanations. It's by intuition at that time.*

Ndebele *I do not plan them, but I will get to talk about them when I discuss with learners during homework corrections at the beginning of each lesson.*

Meyer *It is good to always plan around the integration or differentiation between everyday and scientific ways of explanation for they will always help in solving misconception learners have about certain concepts. But the time to engage with learners is quite limited as you will need to cover the syllabus. My method works for where I cover the content of the day first and leave the time for discussions and questions later.*

Nasimu *Incorporating discussions on how everyday ways of explaining differ or match the scientific ways of explaining is quite important and feasible in a curriculum that is not congested. In the current curriculum, you will not finish the content and prepare the Grade 12 enough for their examinations. The only way is to deal with them as they come up and that discussion should be controlled; otherwise, you will be behind with annual teaching plan.*

The above statements from teachers summarised why in some classes there was limited discussion around the words that could be integrated or differentiated. The teachers especially those in the exit grade have no luxury of entertaining discussion as they race to finish the syllabus in a limited time as the curriculum is congested. The anxiety to fully prepare the learners for examinations was very high among the Grade 12 teachers. The participants had one most important goal to complete the annual teaching plan. Hence, enforcing strategies that enhance meaningful learning was not their major priority.

Not engaging learners to hear their views is ignoring the fact that learners get to into classrooms with an array of misconceptions which are at loggerheads with the scientific views. Airado-Rodríguez, Acedo, González-Gómez, and Niño (2017, p. 499) argue that

> *misconceptions result from the student's attempts to understand their previous experiences resulting from their interaction with their environment and they must be considered in educational practice to design appropriate instructional strategies that will impulse their evolution into more scientific-academic concepts.*

The everyday meaning of words should be in relation to the learners' perspective and not the teachers. Hence, it is noble for the explanations of everyday words to come from the learners and the teacher help in linking them to scientific concepts and integrate or differentiate their everyday meaning to scientific ways of explanation. If the words are coming from the teacher, they should be drawn from everyday use by the same learners who are the recipients of the intended knowledge. Hence, in this context, everyday words and explanations are defined as what the local community commonly uses, and what most people are familiar with. I assert that once the words and explanations are used by the elite class and not accessible to the majority of the populace, they cease to be referred to as everyday explanations.

6.3 Approach 2: Making links between scientific concepts

Besides the linking of everyday and scientific ways of explaining by the teacher and the learners, meaningful learning of scientific knowledge also involves understanding how the scientific concepts themselves are interlinked. Meaningful learning of scientific knowledge requires that learners make sense of numerous interlinked science concepts and develop coherent knowledge constructs (Burrows & Mooring, 2015). I argue that learners can achieve such a deep understanding of scientific conceptual relationships if the teacher is able to present and make the network of concepts explicit during the teaching and learning processes.

As mentioned earlier, this research is aimed at looking at how teachers present their teaching to foster conceptual understanding through knowledge building approaches. Literature has it all about how learners are supposed to interlink related scientific concepts and how they should be able to draw concepts maps to exhibit their conceptual understanding (Cañas et al., 2015; Novak, 2010; Özmen et al., 2009). However, this study focuses on the teacher and not the learner, especially the extent to which the teachers show a conceptual understanding of the interrelatedness of the scientific concepts as they deliver their lessons. Some of the questions addressed in this thesis are: How conscious are teachers to a network of concepts in relation to other topics? And to what extent do the teachers emphasise the importance of such relations to their learners in the teaching of science particularly the electrolytic cells and their essential concepts at the secondary level? The analysis of making links between scientific concepts seek to answer these questions to address the research question; to what extent do teachers use knowledge building strategies in the teaching of electrolytic cells and its important concepts at the senior secondary level?

Concept mapping was used to assess how teachers structure the concepts in their lesson enactment. Concept maps are graphical representations for organizing and depicting knowledge of an individual's long term memory (Jacobs-Lawson & Hershey, 2002; Novak & Cañas, 2008). The knowledge to be acquired should be ordered in such a manner that it fits together in an interweaving scheme (Scott et al., 2011). However, the network of concepts should be structured in a hierarchical manner with the most general concepts at the top of the map and less general concepts at the bottom (Novak & Cañas, 2008). Scott et al. (2011) argue that a deep conceptual understanding will only be achieved when learners appreciate the relationships between organised scientific concepts. For the learners to come to the desired level of meaningful learning, the teacher should be able to enact in his or her teaching the same principle of concept mapping that depicts hierarchically spiral concepts from general to specific.

Consequently, this study is not about assessing learners' conceptual mapping but the teacher's concept arrangement not as he or she has planned but as he/she delivers the actual lesson in a classroom set up. My argument is for learners to be able to organise scientific information as orderly knowledge structures in their schema as maintained by Burrows and Mooring (2015), the teacher should have represented the concepts in the same manner. Hence, my focus is on how the teacher uses interlinking of concepts as a form of knowledge construction to achieve meaningful learning that leads to learners' conceptual understanding.

A total of 15 lessons from five teachers and six classes were video and audio recorded. I drew concept maps in accordance with how the lesson was structured by the teacher. The constructed concepts maps were then discussed with the relevant teacher after he or she was given to read the transcription of the lessons. The transcripts and concept maps were then given to two chemistry PhD colleagues to verify if all concepts were captured accurately. Minor adjustments, especially of omission, were made and I then revised all lessons in accordance with the inputs of each participant and the PhD colleagues. Thereafter, individual teacher case analysis was done, and grade cross analysis is explained below.

6.3.1 Individual case analysis

Johannes Grade 10

Mr Johannes' three lessons on Reactions in aqueous solutions were divided into the dissolution of salts and precipitation reactions (lesson 1), acids & bases reactions (lesson 2) and Redox reactions (lesson 3), of which lesson one was a double period. In the first lesson, the teacher introduced the concept of dissolution. The discussion that followed was centred on the dissolution of solutes. The rules of dissolution were derived from the solubility table. After a whole class discussion, learners were put in groups to answer questions from a worksheet on the dissolution of substances. The arrangement of the desk was conducive for group discussions as learners sat facing each other around two tables. In all the lessons, experimental demonstrations were done by the teacher while learners observed. Figure 6.3 below shows how the lessons were depicted through a concept map.

The lessons on Reactions in aqueous solutions were divided into four major themes, namely; dissolution of solutes specifically salts; precipitation reactions; Redox reactions; and acids and bases. The dissociation of salts in a solvent was linked to the concept of rules of solubilities that was discussed at the beginning of lesson one.

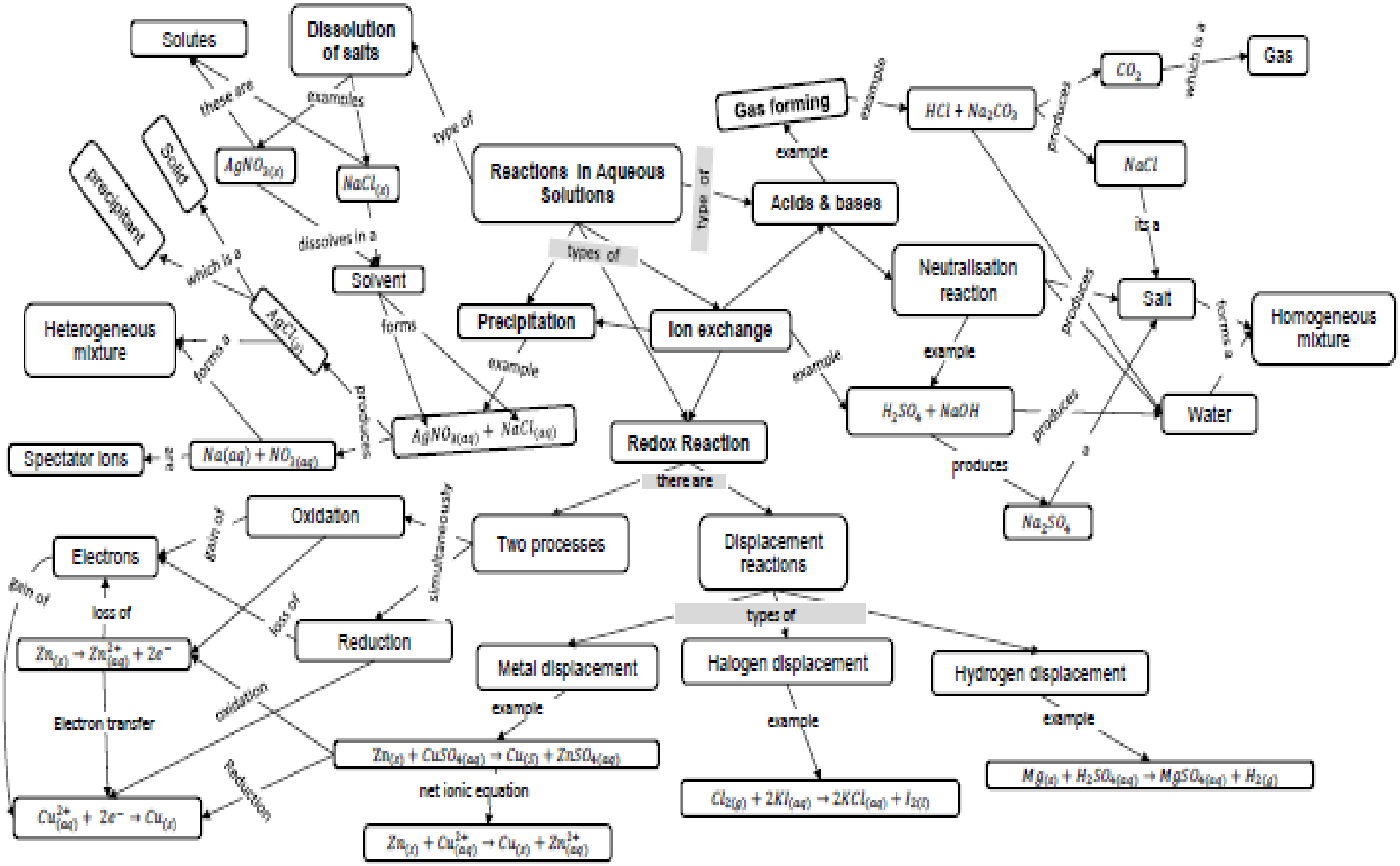


Figure 6.3: Mr Johannes's concept map depiction

Mr Johannes further pointed out that it was of importance to ground learners on the nature of ions in aqueous solutions. Hence, dissociation of solutes in solvents was to be done first after the solubility table. The excerpt below shows part of his argument;

Johannes: *For the learners to grasp ion exchange reactions they should understand the effects of water as a solvent due to its hydrogen bonding on solutes. The structure of water is important as well as how different solutes behave in the presence of water molecules. Learners must appreciate that it is not all solid compounds that dissolve in the water. Hence, learners need to apply solubility rules. That is why immediately after solubility rules and dissociation concepts I covered the precipitation reactions for them to appreciate that all precipitant compounds are not soluble in water. I have found out that it will be then easy to understand, compare and differentiate the other reactions in aqueous solutions.*

The argument was that for conceptual learner understanding of precipitation reactions and other ion exchange reactions the concept of properties of water as a solvent should be explored and the behaviour of other substance or compounds could be investigated after that. Mr Johannes' understanding of how the four thematic concepts (Dissolution of salts; precipitation reactions; Redox reactions; and acids and bases) can be summarised diagrammatically, as shown in Figure 6.4 below.

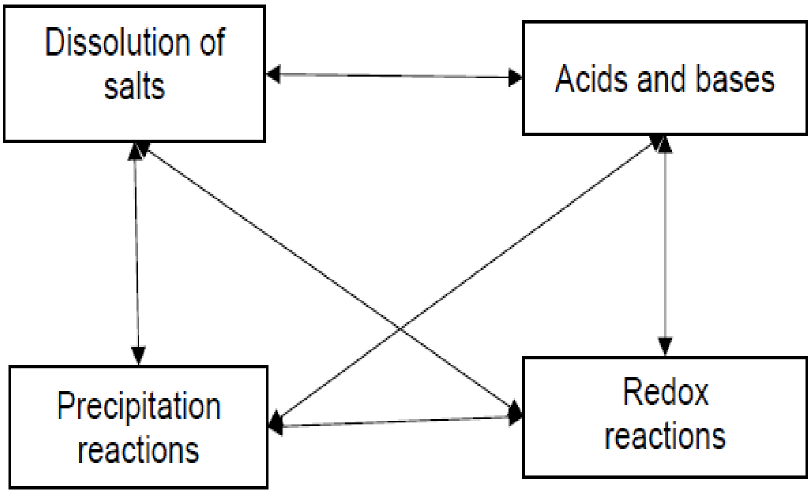


Figure 6.4: Interlinking of thematic concepts

According to Mr Johannes, the topics have a relationship, which centres on the understanding of dissolution of salts after that each reaction in aqueous solution can then be deeply understood. The more one understands any one of the four concepts, the more he or she understands the other four concepts. Hence, learners will be able to differentiate or find similarities among the four types of reactions. This is what Lemke (1990, p. 91) advocated for when he said that “we learn by comparing and interrelating what is said in this part of the lesson to what was said in that part …” Therefore, learners reach conceptual understanding through grasping thematic patterns by comparing the acquired concepts. This was evident in Mr Johannes’ three lessons although in some cases he failed to interlink the concepts for the reason of time.

Mr Johannes followed the principle of the hierarchical arrangement of the concepts from general to specific through the intertwining of concepts, which exhibited his understanding that concepts are not discrete pockets of knowledge. Here is an instance where the teacher successfully linked science concepts in an interwoven manner.

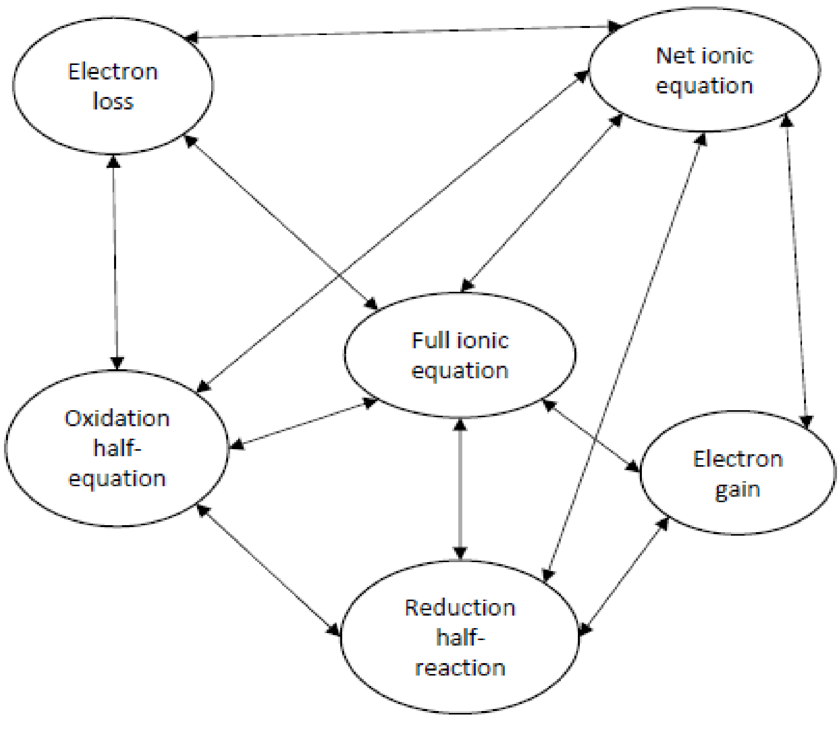


Figure 6.5: Thematic concepts on Redox reactions

Figure 6.5 above shows how the teacher interlinked six concepts of Redox reactions during the last lesson. The definition of oxidation and reduction were defined as the simultaneous loss and gain of electrons, respectively. The teacher further demonstrated the gain and loss using the reaction of zinc and copper sulphate solution (see Figure 6.3), as an example. In the example, he showed how a word equation could be represented symbolically as chemical equations. Thereafter, the equation was transformed into a full ionic equation, then into a net ionic equation from which he drew the half-equations for each reaction. This trend had started in lesson one when he was dealing with precipitation reactions of silver chloride (see Figure 6.3) as an example (see a screenshot picture taken from the video of the lesson below).

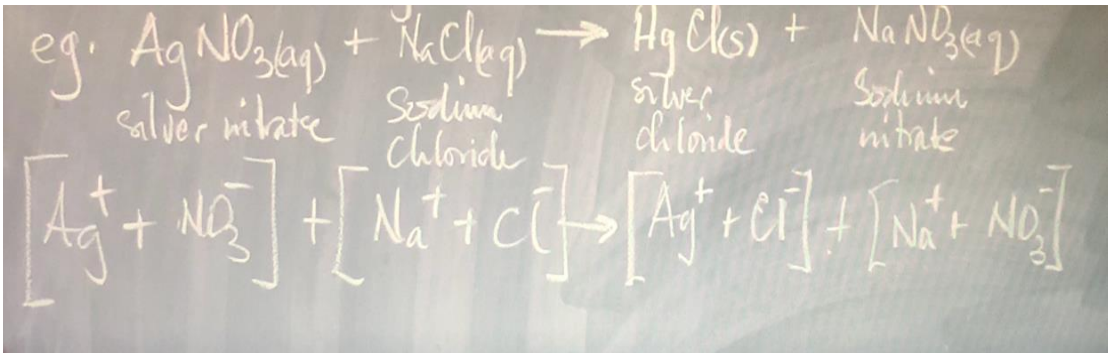


Figure 6.6: Screenshot of precipitation reaction of Silver Chloride.

The teacher drew these equations from the first lesson to the last lesson and the thematic concepts such as net ionic equations, and full ionic equations were repeated time and again, where applicable oxidation and reduction half equations were emphasised. The learners were encouraged to discuss, predict and write these equations in their groups, especially in lesson two and three where he was dealing with acids & bases and Redox reactions, respectively. Lemke (1990) argues that the meaning of the themes must be conveyed by learners using the language of the subject for conceptual understanding to be promoted. The learner must be encouraged to converse with the scientific language for them to learn meaningfully instead of just listening and writing notes without talking themselves. Haug and Ødegaard (2014), in their research with maths learners in the teaching of geometry, found out that conceptual understanding was not ensured when teachers did the talking for the students instead of the student talking. It is of importance that learners construct the meaning of the themes through group discussion as the teacher guides them.

Nevertheless, Mr Johannes was not consistent in his lessons for he only managed to have five scenarios for the three lessons (2 in lesson one and three and 1 in lesson 2).

During the interview, the teacher emphasised the time limitations and the larger classes, especially on experiments. He would have wanted learners to do the experiments themselves and discuss what they were observing and deduce conclusions from the experiments. However, due to time constraints and large numbers of learners in classes he could not let learners do the experiment on their own. Mr Zulu's lesson was the next to be analysed, he also taught the same topic as Mr Johannes to Grade 10 learners but at a different school.

Mr Zulu Grade 10

Mr Zulu's first lesson was on precipitation reactions preceding that of dissociation as perceived from the revision of homework at the beginning of his lesson. Learners had been given an exercise to complete equations of dissociation reactions. One learner managed to give the first example of sodium chloride dissolution in water. After that, the teacher went on to introduce the precipitation reactions, which was then linked to evidence of a chemical reaction and the solubility table. The second lesson, which was a double period, was mainly on the testing of ions using the concept of precipitation reactions. Testing of sulphates and carbonates was done in the third and last period observed. The nature of the relationship of the thematic concept as portrayed by the teacher during his teaching of the three lessons was as depicted in Figure 6.7 below.

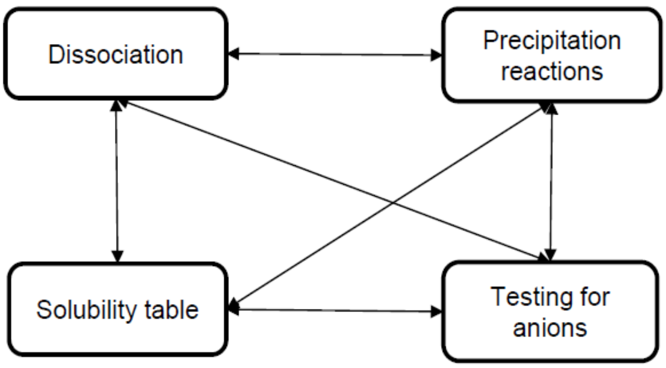


Figure 6.7: Mr Zulu's Interlinking of thematic concepts

Mr Zulu's central themes were solubility table, precipitation reactions and testing of anions and all were linked to the concept of dissociation of ions in aqueous solutions which was done in the previous lessons. However, the solubility table became the dominant theme which guided the understanding of precipitation reactions and testing of anions through experimental demonstrations by the teacher. I summarised the three lessons in a conceptual map as exhibited in Figure 6.8 on the next page.

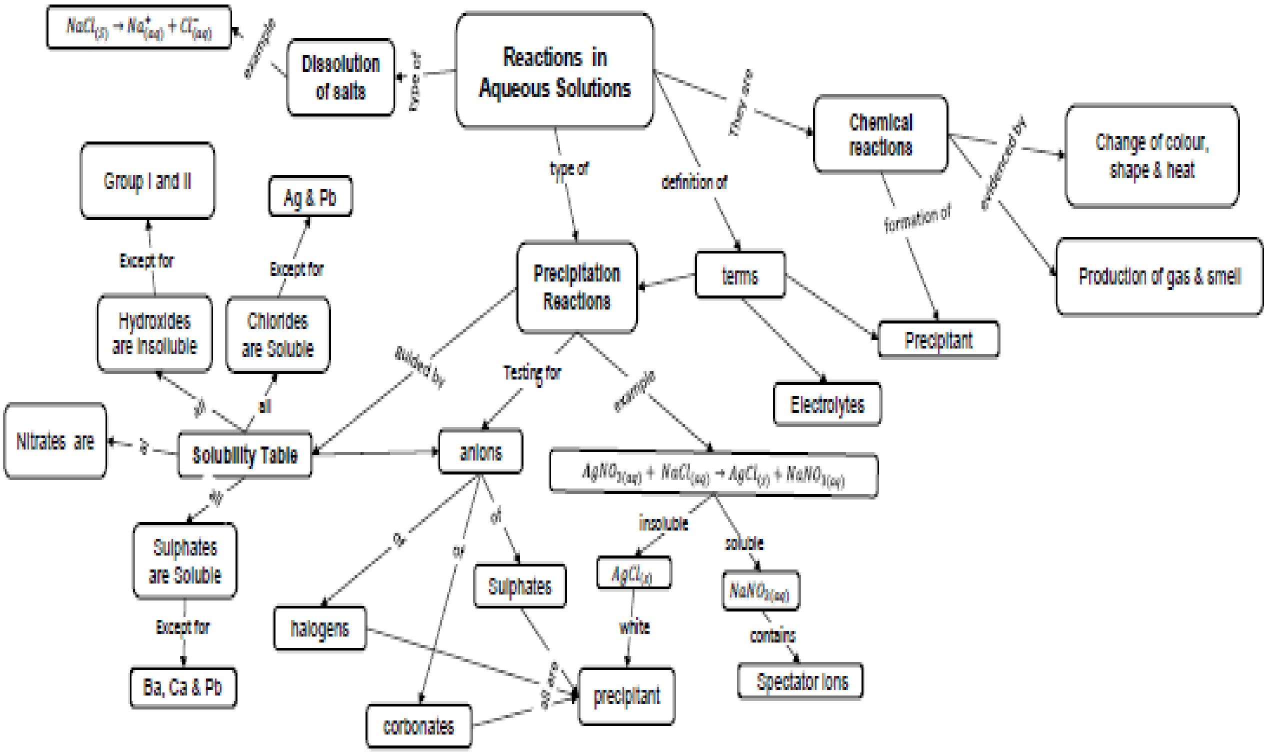


Figure 6.8: Mr Zulu's concept map

The lesson structure indeed followed the hierarchical nature of concept mapping as essential themes were dissected into more straightforward concepts as the lesson progressed. The two concepts which were dealt with in detail were solubility table and precipitation reactions and their applications. However, the lessons lacked interlinking of concepts as the teacher only managed two instances of link-making. During the second and last lesson when the class was discussing precipitation of halides and other anions (sulphates & carbonates), which will be discussed shortly. The nature of engagement between the teacher and the learners was mainly teacher talk punctuated with questions and answers seldom. Demonstration of experiments was done by the teacher with mostly expired chemicals as some of the reactions did not show desired results.

When Mr Zulu was asked about the experiment and the expired chemicals, he lamented the lack of a secure standing laboratory as most of the chemicals are stored in carboards in the classroom. The reader is reminded that this was a satellite school surrounded by squatter camps where crime is rife. Hence, most of the chemicals were stolen through break-ins as thieves look for chemicals to produce drugs. Therefore, the teacher mostly relies on borrowing chemicals from neighbouring schools who usually give them expired chemicals. “I find it better to use those resources for the learners to get an idea of what we discuss practically instead of just theorising everything. Science is a practical subject, but these are the constraints we encounter especially in this school”, reiterated Mr Zulu. Equipment shortages are not that the government does not supply, but it is due to sabotage by the unscrupulous elements within the society to the detriment of the learners.

Mr Zulu exhibited two link-makings, as indicated earlier and only one will be highlighted when the class was discussing precipitation of halides. Much emphasis was put on the use of a table of solubilities to determine which substance will precipitate between the reaction of sodium bromide and silver nitrate solutions. The subject that precipitated was supposed to be identified as that which does not dissolve in water. The discussion can best be summarised by interlinking the concepts diagrammatically, as shown in Figure 6.9 below.

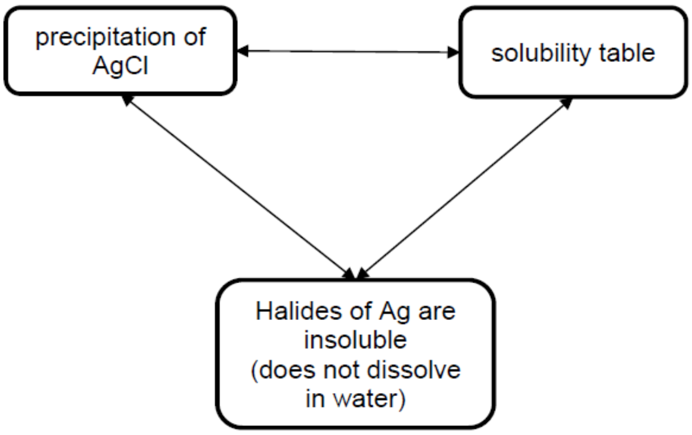


Figure 6.9: Mr Zulu's discussion of precipitation of halides

The teacher successfully linked the three concepts represented in Figure 6.9, and he showed the learners that precipitation of silver chloride and other halides could not be comprehended effectively without referring to the rules found in the solubility table. Mr Zulu emphasised that silver chloride was a solid that did not dissociate or dissolve in water and hence was precipitated out of solution. Although the interlinking supports knowledge building, the teacher did not engage learners to ensure conceptual understanding. This was Mr Zulu’s shorting coming throughout his lessons.

Though he could explain the concepts explicitly to the learners under challenging conditions of lack of chemicals and equipment, Mr Zulu did not utilise the power of social interaction. No group work was done in his lessons. He identified possible concepts linkages, but he linked them himself instead of giving learners the opportunity to make links. The teacher showed learners how word equations and full ionic equations were supposed to be written. Mr Zulu continued to write all the equations on the board. Learners were not given a chance to show their comprehension of the same repeated concept. This assertion is illustrated in the diagrams in Figure 6.10 below, which shows the same equation that was written and discussed by the teacher twice.

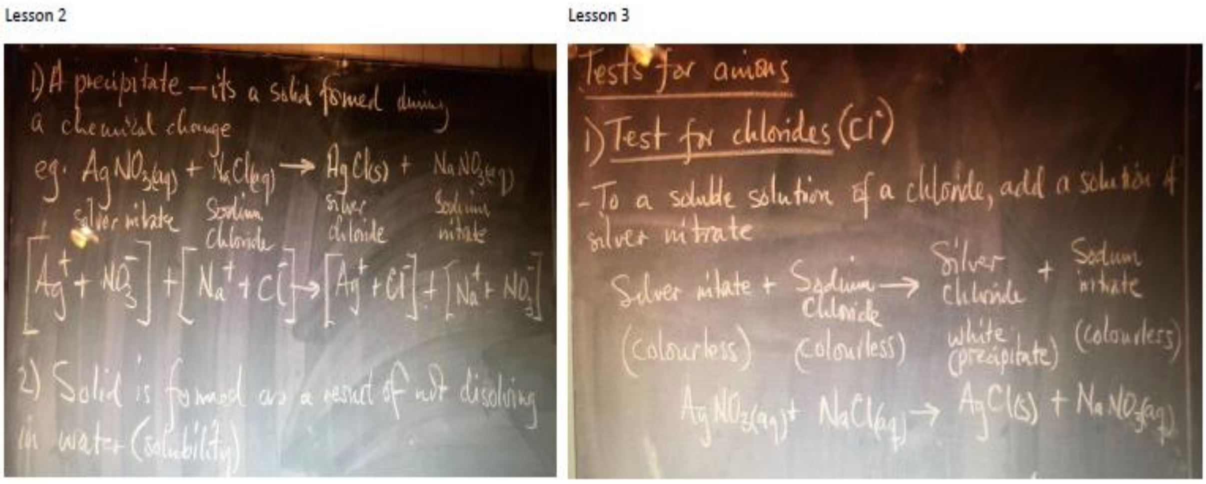


Figure 6.10: The precipitation reaction equation by Mr Zulu

Figure 6.10 above shows two versions of the same equations which are not that different in any case except for the full ionic equation in the second lesson and the inclusion of colours in the last lesson. The argument here is that learners had been exposed to the first equation in the second lesson, and the teacher was supposed to let learners link that initial concept to the testing for chlorides in the last lesson. The teacher successfully fulfils the requirements of concept networking but if learners are not involved in the process meaningful learning is compromised. Compromising of learner engagement does not ensure and guarantee the certainty that learners have understood the concepts. I had to ask the reason behind this kind of approach from the teacher during the interview.

Mr Zulu underscored the fact that he was supposed to engage learners but maintained that he is aware of the facets of learner-centred approach. However, he mourned the fact that periods are very shot, 35 mins each and some of the time is wasted through a change of periods where learners move from one class to the other. By the time they come to him, he would be left with less than 30 mins and to engage in the learner-centred approach you are guaranteed of falling behind your Annual Teaching Plan (ATP). “When those guys from the district come, they would not take your explanation that I was using a learner-centred approach that is why I am behind with my ATP. They always insist that you be on track with it”, said Mr Zulu. He appreciated the effectiveness learner-centred practical demonstrate in fostering conceptual understanding but said that the approach needed time which was not available. To make matters worse, he had Grade 12 and could not take the Grade 10s for extra classes as he was concentrating on the externally examinable exit grade.

The arguments made by Mr Zulu above is evidence that he is aware of the effective teaching strategies that enforce conceptual understanding, but the other circumstances are hindrances to the implementation of such methodologies of teaching. Such circumstances are beyond the teachers’ control and indirectly sometimes coerce the teacher to engage in the transmission method of teaching instead of varying it with other teaching strategies. Mr Johannes and Mr Zulu were teaching Grade 10 classes, and now I turn to Mrs Ndebele and Mrs Meyer who were teaching Grade 11 classes, and I will start analysing Mrs Ndebele’s lessons.

Mrs Ndebele Grade 11

Mrs Ndebele was teaching in a township secondary school. There was an ill-equipped laboratory which was used as a classroom due to classroom shortages in the school. In fact, all the schools involved in this research had no standalone laboratory they were all used as classroom due to high enrolments. However, this school was in the process of being upgraded to be a paperless school. At the time of my data collection, only Grade 12 classes had been upgraded, and the matric (Grade 12) learners had tablets. During my visit to the school, the matric learners were writing trail examinations, and Grade 11 classes were being held in the Grade 12 classes with smart boards. Mrs Ndebele taught all her three lessons using a smart board, but her learners had textbooks and would only be given tablets once they were in Grade 12.

The smart boards were loaded with notes and video lessons for all the subjects. All of her lessons were 60 minutes long. In the first lesson, she dealt with oxidation numbers and rules of oxidation number. The second lesson consisted of oxidation and reduction processes and in the last lesson covered balancing of equations using Redox reactions. Therefore, the topic of Redox reactions was the big idea with three thematic concepts of oxidation and reduction processes, oxidation numbers and balancing of equations. However, each theme could not be covered in the entire lesson but spilt into the next lesson. The teacher carried over the discussion of oxidation numbers into the second lesson and oxidation, and reduction processes were concluded in the last lesson. The thematic relationships are represented in the diagram below.

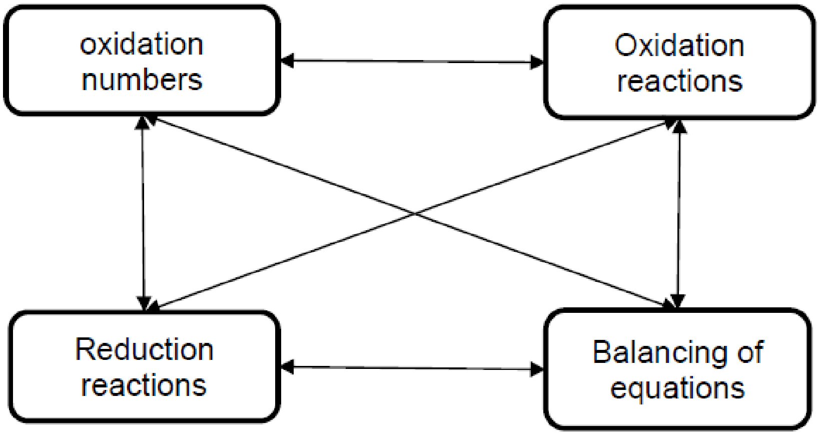


Figure 6.11: Thematic concepts for Mrs Ndebele

Figure 6.10 above shows how Mrs Ndebele linked the three themes .In this diagram oxidation and reductions are separated, but they are not treated as different themes as they simultaneous take place within a reaction.

The first lesson focused on how to assign oxidation numbers using given rules. According to the teacher oxidation numbers is a prerequisite concept for the understanding of Redox reactions. The concept of balancing of equations was done last as the teacher considered it as the application of Redox reactions.

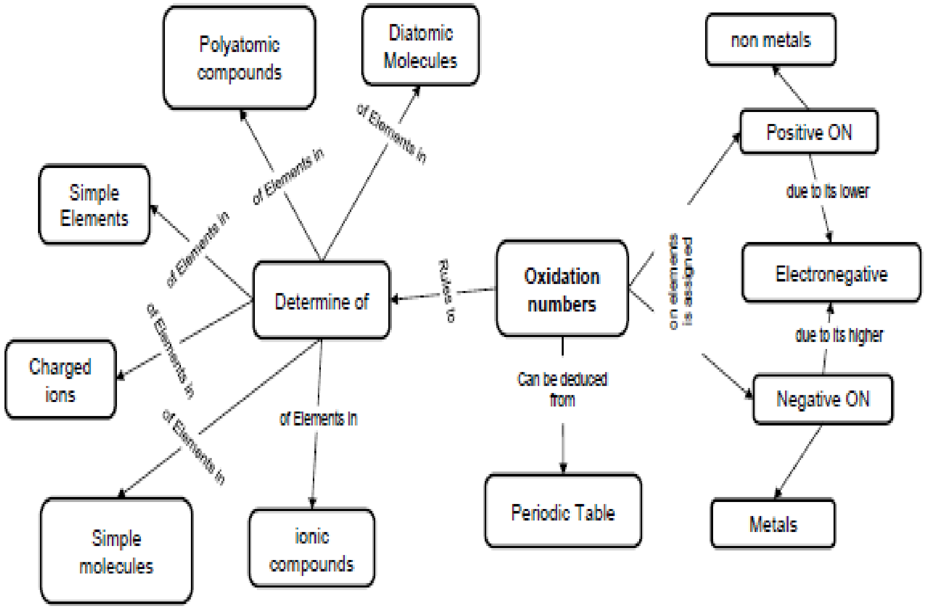


Figure 6.12: Mrs Ndebele's concept map lesson 1

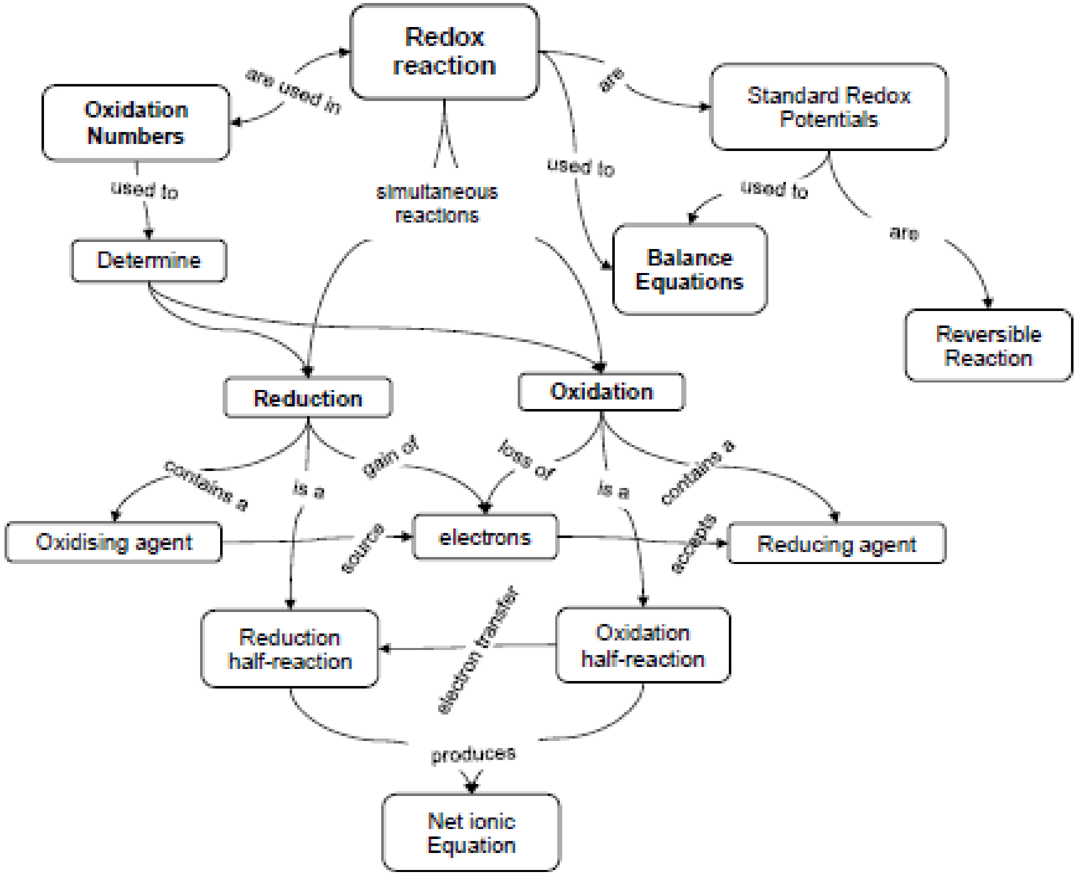


Figure 6.13: Mrs Ndebele's concept map for lessons 2 & 3

The two simultaneous processes (oxidation and reduction) were connected by the process of electron transfer, whereas to determine the species that were oxidised or reduced, one needed to understand oxidation numbers. The reduction and oxidation processes were vital in the balancing of the equation where oxidation numbers were always used. The rest of the concepts and how they were connected by the teacher during her teaching can be best represented by the two concepts maps shown in Figures, 6.12 and 6.13 above.

As can be seen from the concept map in Figure 6.12, Mrs Ndebele's lesson presentations on Redox reactions and oxidation numbers followed a hierarchical organisation of concepts. However, lesson one did not have a network or interconnectedness of concepts as compared to lessons two and three (Figure 6.13). The teacher indicated that it was difficult to link any of the rules of oxidation numbers to any concepts as it was the first-time that learners encountered the concept in their FET phase.

Mrs Ndebele: Teaching of oxidation numbers in Grade 11 is difficult in the sense that you do not expect learners to have a background of the concept as it is introduced to them. I think you have noticed that I spent much time discussing with them the rules. Without the rules then Redox reactions cannot be understood. Unfortunately, in our annual teaching plan, it is allocated less time, but in practice, learners need time to master the rules and apply them. Hence, I had to dedicate much time to it.

Mrs Ndebele indirectly lamented the lack of dealing with this concept earlier as it took much time than allocated by the ATP (Annual Assessment Plan). If the topic had been given ample time in Grade 10, the teacher would have enough time to consolidate the concept with that of Redox reactions. Instead of starting the underlying facts of the concept at this stage. It then militates against the spiral nature of the curriculum, which stipulates that all concepts should be introduced superficially at the beginning of the course and expanded in with more detail in later grades.

In lesson two and building upon the concept of oxidation numbers, the teacher successfully linked the concepts of reduction and oxidation by showing how they were related regarding electron loss by the oxidising agent and electron gain by the reducing agent, as indicated in Figure 6.14 below.

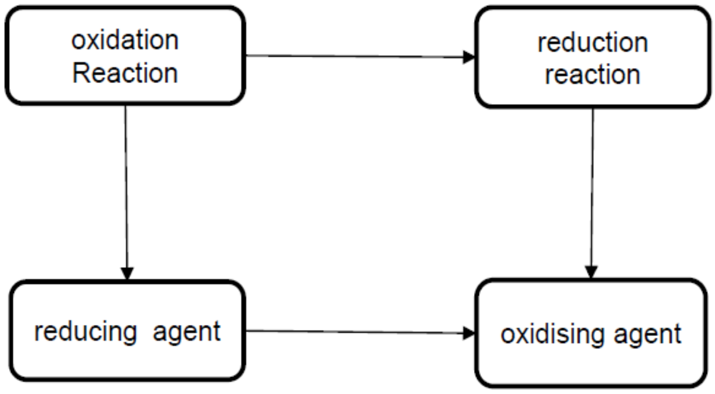


Figure 6.14: Representation of electron flow in Redox reactions

Figure 6.14 above illustrates the electron flow from the oxidation reaction, which contains a reducing agent (electrons donor). These electrons are transferred to an oxidising agent (electron acceptor), a process known as reduction. I found this explanation to be profound but could not say whether the learners understood because they were not engaged in the discussion of the concepts. The teacher defended herself by saying that the concept was quite abstract, and learners needed to be given as it was to minimise the development of misconceptions. Mrs Ndebele's view agrees with Novak (2010) who argues that some scientific concepts need to be taught directly to learners as they are too abstract. In all her three class, Mrs Ndebele used group work for all her class work. She also included one video show and one practical demonstration on the rusting of iron show Redox reactions. However, her Grade 11 counterpart, Mrs Meyer had a different approach, and I will analyse her Grade 11 and 12 lessons concurrently as she displayed the same approach of teaching in the two grades.

Mrs Meyer Grade 11 and 12

In contrast to Mrs Ndebele's school, Mrs Meyer's school was a former group C, situated in a suburban area of a small mining town in the east of Gauteng. The school had interactive whiteboards in contrast to the smart boards of Mrs Ndebele's School. Unlike in the township schools where the government was providing smart boards in the former group C school, it was the School Governing Board (SGB) that was buying the technological equipment. The smart board and interactive white were both touchscreens. Mrs Meyer did not use the interactive whiteboard that much, she only used it to show videos and animations which she sourced herself from YouTube and the world wide web. There was much preparation on Mrs Meyer's side unlike on Mrs Ndebele's part where the smartboard came with preloaded relevant videos and PowerPoint presentations.

Mrs Meyer had to prepare everything on her own and could not have the time to prepare the PowerPoint presentation. She indicated that she was not conversant with Microsoft PowerPoint. Hence, Mrs Meyer preferred to use experimental demonstrations in her teaching to give learners a hands-on experience as her laboratory had adequate chemicals. Mrs Ndebele used videos to show experimental demonstrations to compensate for lack of equipment and chemicals.

Mrs Meyers' three lessons centred on three conceptual themes, namely, oxidation numbers, oxidation and reduction processes (Redox reactions) and balancing of equations and were comparable to Mrs Ndebele's thematic layout, as shown in Figure 6.12 above. She organised the teaching of the other two themes around the concept of oxidation numbers. See the conceptual maps for lesson 1 and lesson 2 & 3 as shown in Figures 6.15 and 6.16, respectively.

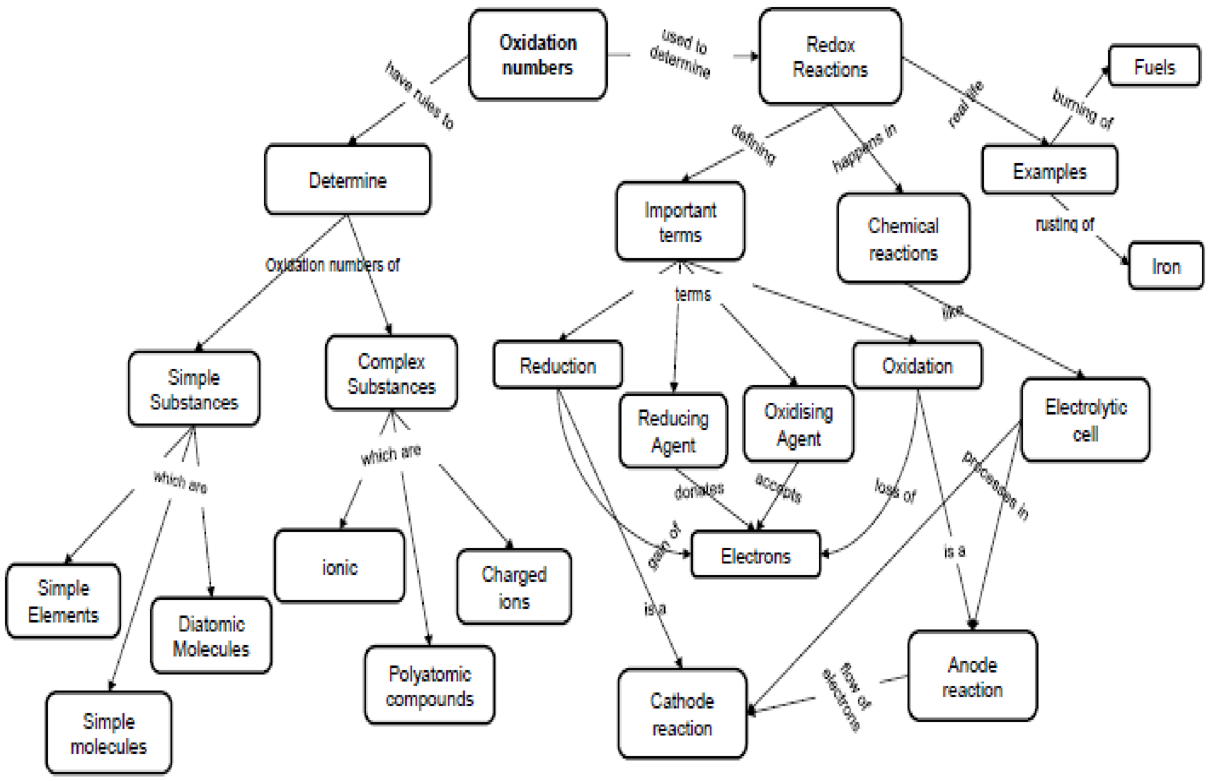


Figure 6.15: Mrs Meyer's Grade 11 first lesson conceptual map

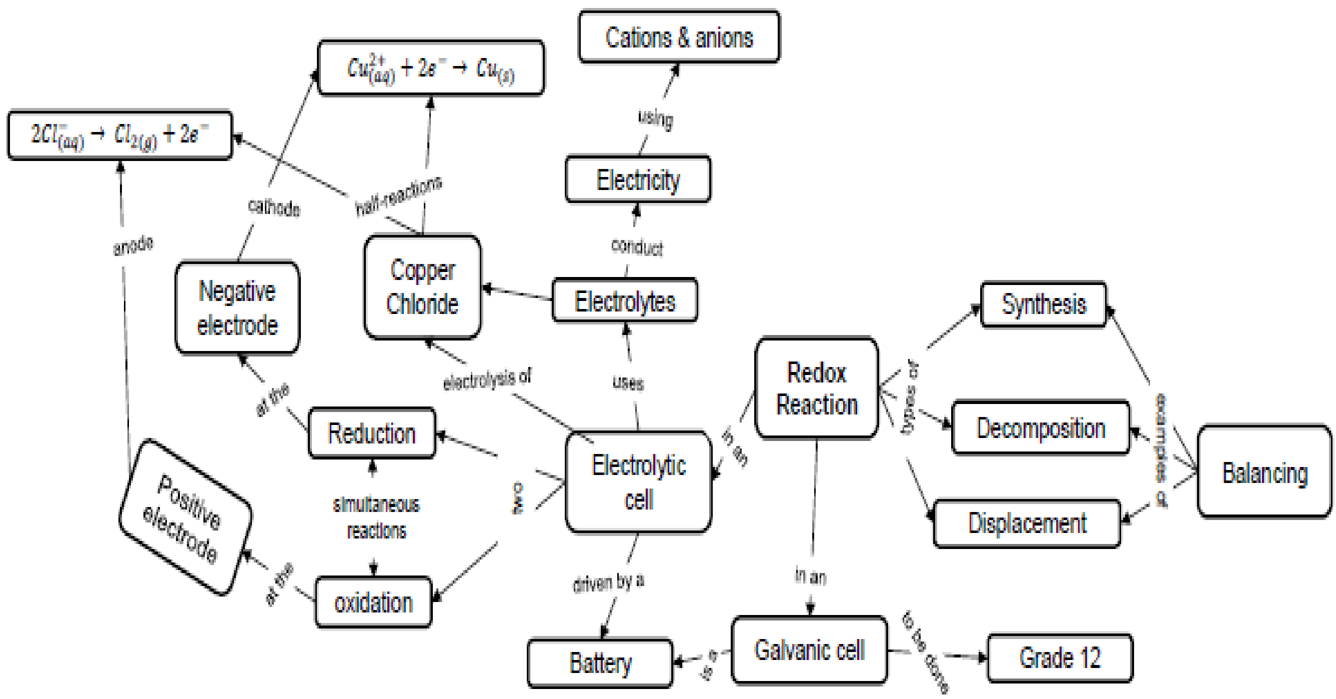


Figure 6.16: Mrs Meyer's Grade 11 second and last lessons conceptual map

Mrs Meyer spent almost the entire first lesson discussing assigning oxidation numbers to elements in different compounds. She argued that it is the focal concept in understanding the redox reactions and electrochemistry at Grade 12, as illustrated in an excerpt of her interview below. She was responding to a probe question on why she spent much time on Oxidation numbers.

Mrs Meyer: I spent most of the time around oxidation numbers to avoid the mistake I was doing in the previous years. Where I rushed through the topic because I did not understand the pressure the teachers and learners in Grade 12 will have, by not fully explaining the concept. Now I am taking both Grade 11 and 12, and I have realised that it is difficult for learners to comprehend electrochemistry in Grade 12 without understanding oxidation numbers. So, I make sure that we cover it extensively in Grade 11.

As argued by Mrs Meyer, oxidation numbers are an essential concept to the comprehension of redox reactions and electrochemistry concepts. Hence, the need for the inclusion of oxidation numbers at Grade 10 level in order to achieve the spiral nature of the curriculum. This is vitally important as “learning is connected, builds upon itself, and grows” (Gibbs, 2014, p. 43).

Instead of starting her lesson with oxidation numbers as was done by Mrs Ndebele, in her first lesson, Mrs Meyer, engaged her learners on how electrons flow in wires and electrochemistry. This is illustrated in the excerpt below.

Line	*Speaker*	*Transcription*
1	*Meyer*	*We are doing redox reactions… We are going to start with the boring stuff …. just a little bit of your terminology…. Redox reactions fall under electrochemistry. Who can explain what electrochemistry is all about? What does the word tell you? Come anybody do not be shy. I know some of you want to say something. Yes.*
2	*Lucky*	*Does it have to do with electricity?*
3	*Meyer*	*eYeah and the rest of it?*
4	*Lot*	*Chemistry*
5	*Meyer*	*Chemistry ne.*
6	*Amos*	*Chemicals.*
7	*Meyer*	*Chemicals that make electricity possible, chemicals and electricity. The next question is who knows what electricity is, anyone?*
8	*Lear*	*Is it not current*
9	*Meyer*	*Yeah, but what is current*
10	*Lear*	*It is I*
11	*Meyer*	*Yeah, but that is a symbol think about it microscopically. What is happening inside a wire? What is electricity what is it? You wanna say something?*
12	*Calvin*	*I know*
13	*Meyer*	*What is it?*
14	*Calvin*	*The movement of electrons.*
15	*Meyer*	*The movement of electrons or the movement of charge. Awesome you actually do know …... Good!*

The lesson was built on learners' contributions from explanations on what electrochemistry is. The teacher successfully probed learners (turns 7 & 11) to come up with the desired explanation. Learners were able to describe the concept of electrochemistry effectively, and in the process, a misconception about the current (turn 10) was corrected. The discussion went for a couple of minutes until the teacher explained in detail the process of redox reactions. Mrs Meyer's probing questions were effectively used to clarify areas learners did not understand.

Using learners' prior knowledge which was drawn most probably from the learners' understanding of Grade 10 concepts or electric current and/or chemical bonding, the teacher successfully constructed the meaning of electrochemistry in a dialogic environment with the whole class. Social constructivist such as Wertsch (1991) and Vygotsky (1978) are of the view that meaningful learning takes places when learners are engaged in a social milieu and when they are taught content that is derived from their previous knowledge. Despite this magnificent start, the teacher went on to teach the entire lesson by transmission where learners were not engaged at all. Learners were given time to discuss class work in groups after she had explained everything on her own, and she would then walk around to each group assisting learners.

Mrs Meyer had few episodes where the interconnectedness of concepts was noticeable in her teaching. In total, she had three scenarios of concept networking one in each lesson. The concept network that was used in the first lesson is shown in Figure 6.17 below.

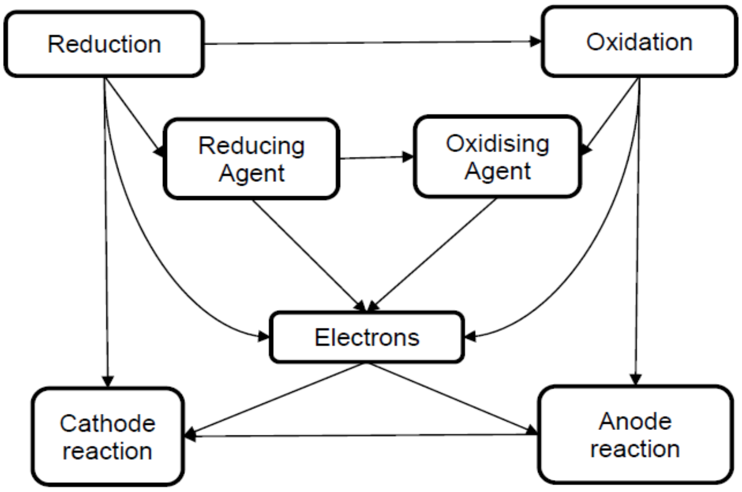


Figure 6.17: Mrs Meyer's conceptual network on redox reactions

The networking of the concepts in Figure 6.16 above was centred on the transfer of electrons. The teacher grounded her learners on the concept of electron flow and the source of electrons. With the help of the electrolytic cell, she described how electrons were transferred from the half oxidation reaction to the reduction half-reaction. In explaining two half-processes taking place simultaneously in the electrolytic cell, Mrs Meyer identified the source of the electrons (reducing agent) which was responsible for the reduction of another species (oxidising agent) the acceptor of the electron. For learners to understand electrolysis, they needed to know that electrons flow from the half oxidation reaction, where the reducing agent was the source of those electrons. The teacher did a commendable job by emphasising the flow of electrons. However, her approach was teacher talk; she explained the interconnectedness of the concepts all by herself without discussing much with learners. Mrs Meyer shared the same reason with her fellow participants that the syllabus was too congested and there was no adequate time to allow discussion with learners. Hence, Mrs Meyer had to fast track her teaching by explaining the concepts herself with little interaction with learners. However, at the end of the lesson, she gave learners an opportunity to discuss as they were doing their classwork.

In her Grade 12 lessons, Mrs Meyer concentrated on three themes, namely, redox reactions, electrolytic cells and applications of electrolysis (Figure 6.18).

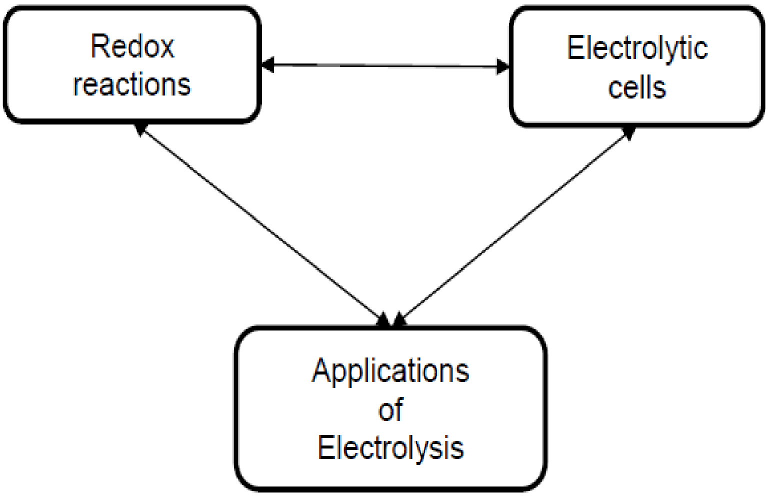


Figure 6.18: Mrs Meyer's Grade 12 thematic concepts

The topic Redox reactions was done as a revision exercise in the first lesson from Grade 11 work. The main focus of the revision was on the definitions of reduction and oxidation reactions, as well as the movement of electrons between the oxidising agent and a reducing agent. Electrolytic cells were done in the first lesson as well, where the teacher compared it with galvanic cells. The diagram below shows the concept map for the second and third lesson.

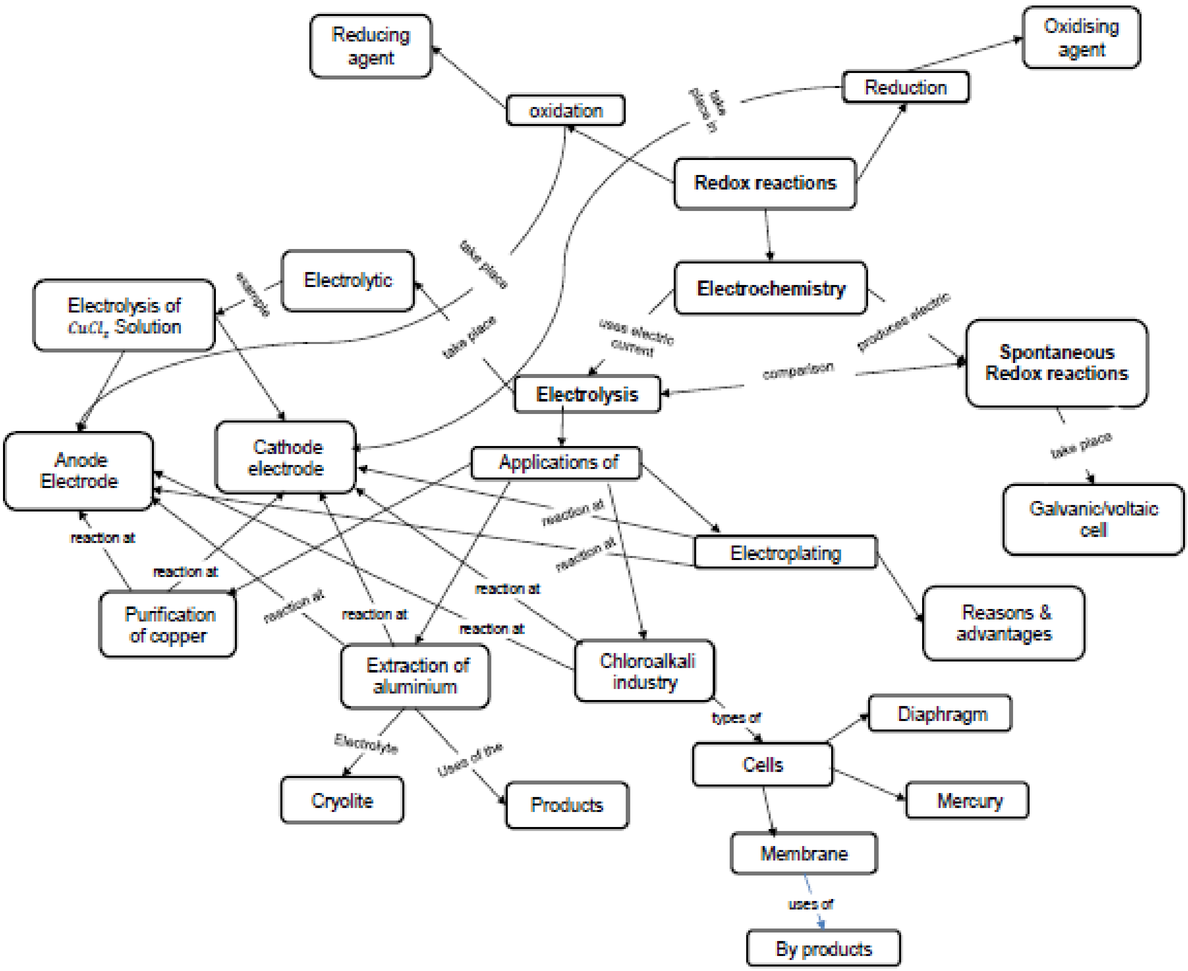


Figure 6.19: Conceptual Map drawn from Meyer's Grade 12 lessons

The second and last lessons were reserved for applications of electrolysis and the concepts covered are, as shown in Figure 6.19 above. In lessons 2 and 3, Mrs Meyer managed a total of six interlinking of concepts. All the concept link-makings were centred on the reactions at the cathode (reduction) and anode (oxidation) as well as the transfer of electrons from a species that donated electrons (reducing agent) to the one that accepted electrons (oxidising agent).

In every application of electrolysis, learners were given the half-reactions that took place at the anode and cathode. As in her Grade11 eleven lessons, Mrs Meyer allowed her learners to discuss their class work after she had delivered her lesson. Generally, her teaching style followed a particular trend. During the introduction of the topic, learners were engaged through brainstorming. In the main part of the lesson, the teacher would do all the explanations and experimental demonstrations of the concepts with limited learner involvement. Learner group work concluded the lesson, where the teacher moved from one group to the other, assisting learners where they had problems. During her interview, she reiterated the fact that she brainstormed with the learners to remind them about essential concepts to remember for the understanding of the topic at hand. However, she believed that engaging in discussion with learners on a new topic was a waste of time as she claimed that would bring about several misconceptions. Mrs Meyer argued that classroom discussions that are intended to correct misconceptions require much time which was usually not available during the teaching time. “You cannot even complete the syllabus in the usual teaching time; you must take learners for extra classes to complete it”, she explained. These sentiments were echoed by Mr Masutha who said that without Saturday classes for the Grade 12 learners the syllabus would not be complete at all.

Mr Masutha Grade 12

Mr Masutha also taught at a former group C school like Mrs Meyer. He was using the chemistry laboratory as a teaching classroom. He had a laptop, data projector and a screen instead of an interactive whiteboard like Mrs Meyer. However, he preferred to use the chalkboard instead of PowerPoint presentations, as he argued that one must have adequate skills and time to prepare presentation slides. Mr Masutha was observed teaching three lessons, where he covered electrolytic cell processes and industrial applications of electrolysis, as shown in Figure 6.20 below.

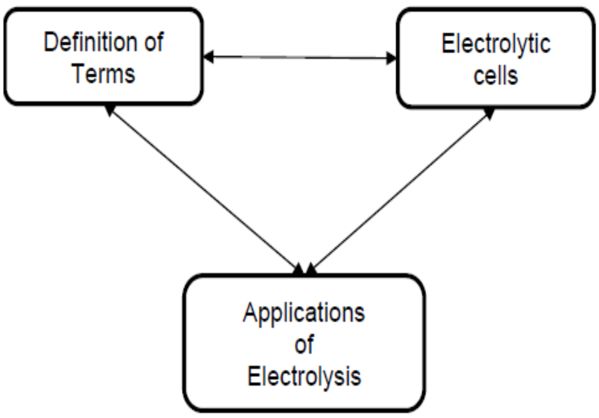


Figure 6.20: Mr Masutha's thematic conceptual diagram

Definition of terms was done as a bridging topic between the electrolytic cell and redox reactions by Mr Masutha. During the whole class discussion concept such as oxidation, reduction, electrolytes, oxidising and reducing agents, cathode, anode and electrolysis were discussed in the first lesson. The second lesson dealt with the concept of electrolysis where a demonstration of decomposition of copper sulphate solution was done. In the last lesson, which was a double period, the teacher concentrated on the applications of electrolysis where the purification of copper and electroplating were demonstrated to the class. Interestingly, in all his experiments the teacher involved learners from the connection of the circuit until observations. Learners discussed the observations during the experimental demonstrations, which learners loved to do and were correcting each other whenever there was a mistake. However, Mr Masutha only engaged learners in whole class discussions as he resented group work, especially with his Grade 12 learners. When he was asked why he resented group work discussions with the Grade 12 learners, he had this to say.

Mr Masutha: At this stage of Grade 12 you are not supposed to be teaching learners how to behave in class and in group discussions. By now it should be embedded in them as there is no time now to teach them what to do in group discussions. We are racing against time to finish the syllabus. As it is now, they will write the preliminary examinations without doing fertilisers according to the ATP. Therefore, I must call them for Saturday classes to finish the syllabus. So, I cannot afford to waste time by doing group work and forcing learners to stick to their group discussion objectives. This skill should be inherent in them from lower grades, but they rarely concentrate on the work at hand during group work.

Therefore, Mr Masutha preferred controlling the whole class discussion and sped up the pace of covering the syllabus. Even during the experiments, learners were always guided by the teacher on how to set up the apparatus. On the question of how he ensured meaningful learning during his teaching, Mr Masutha acknowledged that it was difficult to ensure meaningful learning as he was mainly concerned with finishing the syllabus. He would only know the extent of learner understanding during past examination question paper discussions with learners. Hence, his method of teaching was to complete the syllabus with the learners and would ensure learners pass examinations through question revision and drilling of answering of questions. Nevertheless, the arrangement of his concepts was hierarchical and showed an understanding of building knowledge from using conceptual relationship (see Figure 6.21 below).

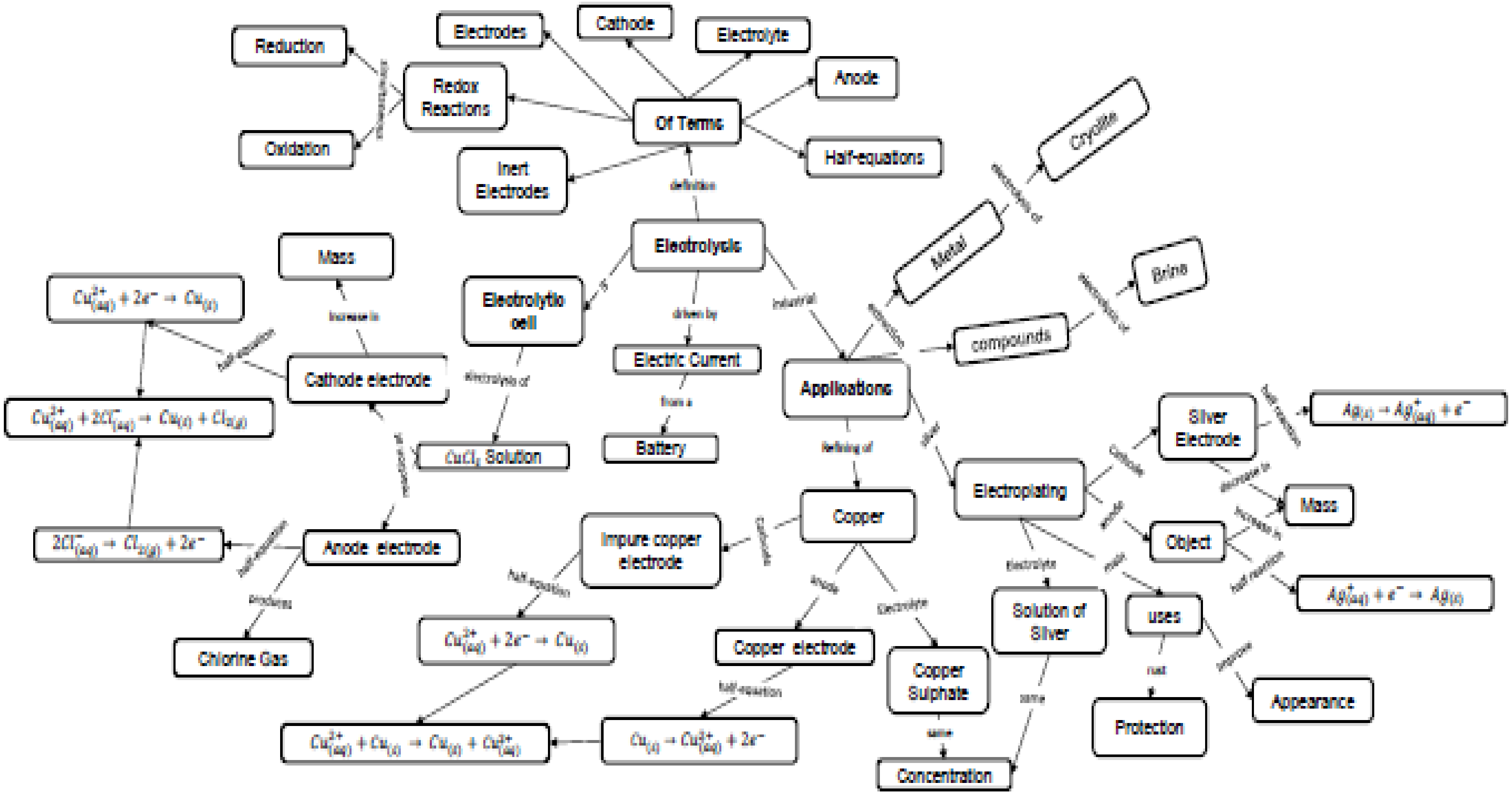


Figure 6.21: Concept map for Mr Masutha's Grade 12 lessons

Mr Masutha used one networking relationship of concepts, which was repeated six times with different applications of electrolysis, as shown in Figure 6.22 below.

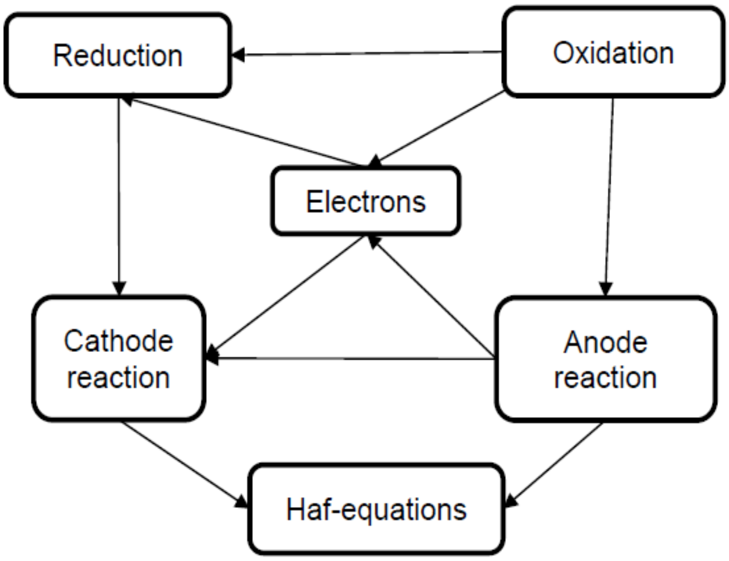


Figure 6.22: Mr Masutha's generally conceptual network in all three lessons

Mr Masutha's emphasis was on writing correct half-equations derived from interpreting reactions taking place at the electrodes. The teacher stressed much on learners identifying the two reactions taking place at the anode and cathode regarding gain and loss of electrons. However, during the last lesson when the class was discussing electroplating, it was evident that learners were not grasping and understanding the concepts. The discussion arose after a demonstration experiment on the electroplating of an object with copper metal. The teacher was asking questions on which electrodes are electrons being gained or lost. Learners successfully identified the electrode where oxidation took place but had difficulty in identifying the reducing agent or oxidising agent. The excerpt below captures the discussion between the teacher and learners about species that will be gaining electrons at the cathode.

Turn	*Speaker*	*transcription*
110	*Mr Masutha*	*…… right so what will be gaining electrons at the cathode? Who can tell us what will gain electrons at the cathode?*
111	*Clyde*	*The copper metal.*
112	*Lerato*	*The object.*
113	*Mr Masutha*	*The object? Can you read what you wrote under the reaction on the anode?*
114	*Thato*	*Copper metal. (Learners talking to each other about the question).*

115	*Mr Masutha*	*Shhhh, if you have an answer raise your hand. Am saying which, what will gain electrons at the cathode, yes (pointing to Graham).*
116	*Thato*	*The object*
117	*Mr Masutha*	*She is saying the object any other opinion*
118	*Mercy*	*Copper metal.*
119	*Mr Masutha*	*Is there copper metal at the cathode?*
120	*Class*	*No.*
121	*Mercy*	*No. Eish the object.*
122	*Mr Masutha*	*The object?*
123	*Clive*	*Copper II plus, no am lying sulphate gains.*
124	*Mr Masutha*	*So, you are just writing, and you do not understand what you are writing because you wrote the answer already in the notes. Mary can you read what you wrote under reaction at the anode.*
125	*Mary*	*The copper II plus ions*
126	*Mr Masutha*	*Yes.*
127	*Clive*	*Uyazi (you know)*
128	*Mr Masutha*	*Where are you getting lost guys? …….*

It is evident here that learners were guessing or that there was a misconception that an electrode receives electrons. The electrode is the object that conducts electrons. Those electrons were to be received by an oxidising agent that will deposit itself around the object thereby coating it. The learners failed to understand that cations which are an oxidising agent complete the electric circuit by receiving electrons at the cathode, a misconception common with high school and college students (Garnett & Treagust, 1992; Kong, 2016). The above extract shows that rushing through concepts without the deep involvement of learners and just giving them notes does not result in deep understanding. In turn 124, the teacher acknowledges that learners write notes without understanding. If learners are not sufficiently involved it becomes difficult to ascertain whether they understood or not until such situations happen where the teacher asks questions to check for understanding. As long as learners are not involved in identifying the relationships between concepts, teacher's conceptual link-making does not culminate in meaningful learning. In this research, all teachers were successfully linking related scientific concepts, although they varied in the number of relationships interlinked as shown in the table below.

Table 6.3: Number of conceptual links per grade per teacher

Teacher	Grade	Number of conceptual

		networks made
Johannes	10	4
Zulu	10	3
Ndebele	11	5
Meyer	11	7
Meyer	12	6
Masutha	12	6

The table above displays a general trend that shows that as you move up the grades the number of episodes where interlinking of concepts is made increases in this research. Mrs Meyer in Grade 11 had the highest number of links, and this could be attributed to the fact that she ventured into Grade 12 electrolytic cells, which are not emphasised at Grade 11 level. She gained more link-makings as she was connecting concepts of the anode and cathode reactions. As indicated above, the link-making could be immaterial if learners are not sufficiently involved in their establishment. Could this trend of non-learner involvement be consistent in other knowledge building approaches? Let us find out when analysing the next approach of making links between scientific concepts explanation and real-world phenomena.

6.4 Approach 3: Making links between scientific explanation and real-world phenomena

The primary assumption of this approach is that the learner must appreciate the relationship between scientific ideas and the real world when the teacher saturates scientific concepts with the tangible (Scott et al., 2011). The approach calls for the teacher to construct connections between scientific concepts and real-world phenomena by skillfully choosing the real-life experience due to its potential interest and relevance to learners.

As indicated in the literature review chapter, this study focuses on the situated interest, which relates to a real learning environment that can be varied in accordance to the teacher’s chosen method of teaching (Rannikmae et al., 2010). Park (2015) argues that learners are more attentive and obtain more knowledge when they have an interest in a topic or an activity. Hence, the teacher should strive to make lessons more interesting to the learners as much as possible.

The teacher also should be able to connect science constructs to real-world issues (Cetin-Dindar, 2016), that is motivating science learners through relevance. According to Rannikmae et al. (2010), real-life situations become relevant when it is considered from the learner's standpoint, meaning it should be a phenomenon that is encountered in learners' everyday life. Consequently, if the phenomena are beyond the learners' world of existence, they cease to be relevant even though they may be relevant to the teacher. Teachers are, thus, called upon to be familiar with the related real-life scientific situations or events within the learner's community.

This study looked at the activities the teachers incorporated in the teaching and learning process that stimulated learner interest as well as the relevancy of the real-life situations to the learners. The table below shows the frequency of episodes of either interest activities or real-life situations per individual teacher per grade.

Table 6.4: Interest and relevance frequencies for individual teacher

Grade	Teacher	Interest	Relevance	Total	Learner Involvement	% of learner involvement
10	Johannes	2	2	4	2	50%
10	Zulu	2	2	4	1	25%
11	Ndebele	1	1	2	1	50%
11	Meyer	1	2	3	1	33%
12	Meyer	2	7	8	1	13%
12	Masutha	3	6	9	8	89%
	Total	10	20	30	14	47%

There were a total of 10 practical demonstrations in all six classes, and all of them had the potential to arouse learners' interest in the subject. Only in Mr Masutha's class were learners allowed to manipulate the apparatus during the demonstrations of practical work .The rest of the teachers did demonstrations, while learners were onlookers.

Twenty scientific concepts were related to everyday life. Mrs Meyer and Mr Masutha (all with Grade 12 learners) had the highest frequencies of relevance link-making.

Mrs Ndebele made only one link-making of relevance, and the rest of the teachers managed only two per teacher per grade. About 47% of the total links made between scientific explanation and real-world phenomena involved learners. More than half of those links were made in Mr Masutha's classes. The rest of the teachers managed only one link-making except for Mr Johannes who had only 2.

Although most of the learners in the five schools were amused, especially by the results of the experiments, Mr Masutha's learners showed a lot of enthusiasm whenever they were doing the demonstrations. The excerpt below narrates an episode where two girls were demonstrating an experiment on electroplating. While the class was discussing the movement of ions in solution, the two learners who were demonstrating moved their hands and the electrodes dipped in the electrolytic cell were in conduct. The discussion after that was captured in the extract below.

Line	*Speaker*	*Translation*
80	*Santos*	*Aaah guys they must not touch. Can I hold the electrodes, please?*
81	*Ester*	*You guys you had your chance yesterday. (girls refused with the electrodes)*
82	*Masutha*	*Can you take them out and see what has happened?* *(learners take out the electrodes from the beaker)*
83	*Thato*	*Nothing*
84	*Titus*	*There is something guys*
85	*Thato*	*Oooh yes there is something (the whole class is in agreement by uttering different sounds of amusement)*
86	*Masutha*	*Do you see that copper is being deposited there?*
87	*Class*	*Yes*
88	*Santos*	*Give it more time Sir.*
89	*Masutha*	*But, more time that's what we do not have. Can you put them back?*
90	*Mary*	*Yes.*
91	*Masutha*	*So, copper is being deposited at the cathode, and after some time it is coated with copper, isn't it? The more time you allow this to happen, the thicker the coating, you understand. ……*
92	*Kizito*	*So do they do like this in the industry, exactly like this?*
93	*Masutha*	*That is the same thing, but they will be doing it in large quantities because you cannot operate an industry where you are producing small quantities like this. That is the central concept behind electroplating.*
94	*Kizito*	*So we can make our own gold?*
95	*Masutha*	*Yes, you can coat something with gold. Can you take it out now and let us see?* *(the electrodes are taken out of the electrolyte solution)*
96	*Class*	*Oooh*

Only Mr Masutha managed to achieve deep learner involvement in the whole class discussion. The rest of the participating teachers barely involved learners in this particular linking-making. Although the time of completing the syllabus is a critical factor, Mr Masutha could effectively keep learners' interest high and engaged learners in real-world phenomena. Clearly, time is not the only critical factor but the quality of the teacher's pedagogical skills to effectively motivate learners and give real-life situations that are relevant to learners. Despite Mrs Meyer scoring eight link-makings during her three lessons, only one was learner centred and the rest she made the links herself. She made these links during her transmission or lecture method session before giving learners time to discuss in groups. For in-depth, meaningful learning to be attained, the teacher's expertise and deep understanding of the link-making is a paramount requirement (Scott et al., 2011). Therefore, teachers need training and development to gain knowledge and skill of learner engagement in the social plane using pedagogical linking tools. Scott et al. (2011) argue that teachers must only introduce prompts for link-making in the social plane and learners should make links through social interaction for deep understanding to be achievable. Figure 6.23 below exhibit a graphical representation that compares the frequency of link-making to arouse interest and the use of relevant real-world phenomena.

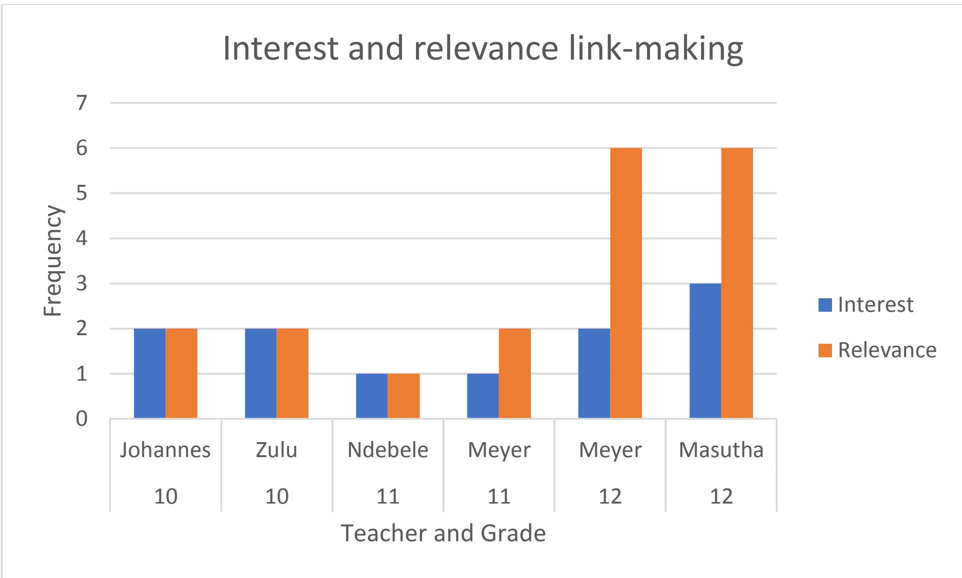


Figure 6.23: Frequencies of scientific concepts linked to Interest and relevant

The above graph indicates a general increase of both link-makings from Grade 10 to 12 except for Mrs Ndebele who was teaching a Grade 11 class at a paperless township secondary school. Despite the fact that she had all the technology at her disposal, she neither drew learners' interest in the subject nor revoked relevant real-life examples. On the contrary, Mr Masutha who did not have such advanced technological equipment managed to have a high frequency of link-making between scientific explanations and real-world phenomena. Hence, meaningful learning is only achievable when the teacher has profound knowledge and skills to engage learners in class or group discussions.

6.5 Conclusion

The first three approaches of pedagogical link-making to support knowledge building have been analysed and discussed in this chapter. These are making links between; everyday and scientific ways of explaining, scientific concepts and scientific explanations and real-world phenomena

In the first link-making, it was found that most of the teachers used pedagogical linking making to integrate than to differentiate between everyday and scientific ways of explaining. It was found that the use of both integration and differentiation increased from Grade 10 to 12. However, the way the two approaches were different from one teacher to the other can only be attributed to the skill and everyday vocabulary of individual teachers. Furthermore, it was found that teachers did not entertain the discussion of everyday ways of explaining because of the fear of misconceptions that will take time to resolve within the confines of the lesson. Teachers alluded to the fact that such discussions need more time which is not possible with the current timeline of the annual teaching plan. Hence, the majority of the integrations and differentiations were done by the teachers without the involvement of learners. When learners are not engaged in the teaching and learning process conceptual understanding is not assured. Only two teachers Mr Johannes and Mr Masutha involved learners integrating scientific ways of explaining with everyday ways of explaining. Hence, Mr Johannes and Mr Masutha lessons learners exhibited traits of conceptual understanding as evidenced by learner contributions in the class or group discussions.

The second link-making I observed that teachers presented well-connected concepts that were developed from relevant scientific themes. From each teacher's lesson, conceptual themes were sequentially and logically arranged. The way teachers linked the scientific ideas one to another demonstrated a deep understanding of their content knowledge. Three teachers, Mrs Meyer, Mr Johannes and Mr Masutha expertly presented hierarchical and conceptually coherent lessons more than the other two teachers Mrs Ndebele and Mr Zulu. However, learners were not actively involved in the link-making teachers were the dominant link-makers. No matter how presentable the lesson is, if the learners are not fully engaged and do not participate in the linking of scientific concepts as presented by the teacher, meaningful learning or conceptual understanding may not be guaranteed. Such was the case in this research that teachers seldom involved their learners in the teaching and learning process compromising the attainability of conceptual understanding.

In the third link-making, I found that Grade 12 teachers had the highest link-makings made between scientific explanation and real-world phenomena than the Grade 10 and 11 teachers put together. However, only one teacher (Mr Masutha) managed to have deeper learner involvement through practical demonstrations and whole class discussions. The other four teachers did not engage learners to that magnitude especially on practical work due to lack of adequate resources, for example on apparatus and chemicals. The major problem was that teachers did not give learners sufficient time to engage whether with conceptual phenomena or with manipulation of science equipment and chemicals. It was found that only 47% of the activities involved learners. Although teachers understand the scientific content knowledge, they lack the skills or knowledge building capabilities that culminates in meaningful learning.

The following chapter addresses the three remaining approaches of knowledge building, namely, making links between different scales and levels of explanation; making links between modes of representation and analogous cases.

CHAPTER 7

The use of multimodalities and multilevel of thought

7.0 Introduction

As stated earlier the second form of pedagogical link-making to support knowledge building consists of six approaches, of which the first three approaches were analysed in chapter 6. This chapter addresses the following issues: making links between modes of representation, moving between different scales and levels of representation, and analogical link-making. However, my data only met the criteria for two of the approaches. None of the participating teachers in the study used analogies in their teaching. The analysis of these two approaches attempts to answer the research question on knowledge building, which is: “to what extent do teachers engage in meaning-making strategies in the teaching of electrolytic cells and its fundamental concepts at the senior secondary level?” I present the findings for the approaches: “making links between modes of representation” and “moving between different scales and levels of explanation”.

7.1 Approach 4: making links between modes of representation

Science concepts cannot be explained through verbal language only, but through modes of representation to facilitate visualisation. According to Ainsworth, Prain, and Tytler (2011), visualisation is integral to scientific thinking. Modes of representation such as mathematical, graphical, diagrammatic, pictorial, videos, photographs, chemical equations and an array of other modalities of representations can be used to explain concept relationships and to arouse learner interest (Ainsworth et al., 2011; Lemke, 1998). Learners should be exposed to these different visual representations to foster meaningful learning of science concepts. McDermott and Hand (2013) argue that the use of multimodal representation enhance conceptual understanding by linking unseen processes with what they can see. Hence, the use of modes of representation helps learners to visualise the verbalised abstract scientific concepts. Instruction or scientific teaching approaches must involve the use of multimedia representations to foster learner conceptual understanding.

Teachers are called upon to ensure deep learning of scientific concepts through making links between different modes of representation. Scott et al. (2011) argue that teachers should be able to support learners in integrating different representations of scientific concepts. Lemke (1998, p. 250) posits that “verbal discourse of the classroom itself is often not fully comprehensible without co-reference to visual, gestural, or mathematical representations”. However, for meaningful learning to take place, learners must be involved in making links to these multimedia demands and should not be limited to just interpreting the visual media.

The interpretation of the modes of representation is pertinent to understanding science concepts. Deep conceptual understanding is enhanced when learners are systematically encouraged to create their visual images of the learned scientific phenomena (Ainsworth et al., 2011). Hence, during the teaching and learning process, the learner should be fully involved in interpreting and creating visual representations of scientific phenomena to augment learner conceptual understanding. The analysis of this approach will unveil whether learners we afforded opportunities to link concepts with different modes of representations.

Eighteen lessons were analysed separately to determine different modalities that were used by each teacher during the teaching of electrolytic cells, redox reactions and reactions and aqueous solutions concepts. In total, teachers used seven different kinds of modes of representations, namely, pictorials, diagrams, chemical equations, mathematical expressions, tables, videos, and models. The modes of representation that were used by the teachers are shown in Table 7.1 below.

Table 7.1: Modes of representations as used by each teacher per lesson per grade

Teacher	Lesson	Pictorial	Diagrams	Chemical Equations	Mathematical Expressions	Videos	Tables	Models
Zulu	1	0	0	2	0	0	1	0
	2	0	0	3	0	0	1	0
	3	0	0	4	0	0	0	0
	Total	**0**	**0**	**9**	**0**	**0**	**2**	**0**
Johannes	1	0	2	3	0	0	2	0
	2	0	5	9	0	0	0	0
	3	0	2	3	0	0	1	0
	Total	**0**	**9**	**15**	**0**	**0**	**3**	**0**
Ndebele	1	0	1	3	6	1	2	0
	2	0	2	3	3	1	0	0
	3	0	0	2	2	0	0	0
	Total	**0**	**3**	**8**	**11**	**2**	**2**	**0**
Meyer	1	2	0	3	6	0	1	1
	2	0	0	4	2	0	0	0
	3	2	0	7	2	0	0	0
	Total	**4**	**0**	**14**	**10**	**0**	**1**	**1**
Meyer	1	0	1	6	0	1	1	0
	2	1	1	1	0	0	0	0
	3	0	2	4	0	0	1	0
	Total	**1**	**4**	**11**	**0**	**1**	**2**	**0**
Masutha	1	1	2	3	0	0	0	0
	2	0	1	6	0	0	1	0
	3	0	3	1	0	0	0	0
	Total	**1**	**6**	**10**	**0**	**0**	**1**	**0**
Grand Total		**6**	**22**	**67**	**21**	**3**	**11**	**1**

It is evident from the numbers in Table 7.1 that chemical equations were the most used representation of all the participating teachers with a frequency of 67 and the use of diagrams was second with a frequency of 22. Chemical equations were used extensively with an average frequency of approximately 11 and a minimum frequency of 8 by Mrs Ndebele. Mr Johannes scored the highest at 15. However, no particular trend could be deduced in the use of chemical equations either per topic or per grade. The use of chemical equations can be attributed to the teacher's prowess, curriculum expectations among other factors in using such a representation.

Diagrams were not used as many times as chemical equations. All the teachers except Mr Zulu and Mrs Ndebele used the diagrams.

Mathematical expressions were the third most frequently used form of representation at 21. What was interesting was that it was only used by the Grade 11 teachers in teaching calculations of oxidation numbers; mainly in the first lesson. The rest of the topics in other grades did not require the use of mathematical tools by the CAPS document.

The use of tables ranked 4th with a frequency score of 11 and was one of the two representations used by all teachers in all grades. The other three representations, namely, pictorial representation, videos, and models were barely used by one or two teachers only. Pictorial representations were used by Mrs Meyer and Mr Masutha; videos were utilised by Mrs Meyer and Mrs Ndebele. Mrs Meyer was the only one who used the model of representation. The representations that were least used by teachers will be analysed under case by case analysis. I now illustrate the four most frequently used representations (see Table 7.2).

Table 7.2: Total frequency scores per teacher for the four most used modes of representation

Teacher	Grade	Mathematical Expressions	Diagrams	Chemical Equations	Tables	Total
Zulu	10	0	0	9	2	11
Johannes	10	0	9	15	3	27
Ndebele	11	11	3	8	2	24
Meyer	11	10	0	14	1	25
	12	0	4	11	2	17
Masutha	12	0	6	10	1	17
Total		21	22	67	11	

As evident from Table 7.2 above, there is no significant trend among grades. Grade 10 teachers had a total frequent of 38 modes of representations, Grade 11 teachers had a frequent score of 59, and Grade 12 teachers had a total frequent scored of 34. There is no trend suggesting that these modalities are topic depended except for mathematical expressions in Grade 11.

Mathematical expressions were only used in Grade 11 on the concept of oxidation numbers. As indicated in Chapter 4, the concept of oxidation numbers was only done in Grade11. Its absence in Grade 10 means that there no topic under reactions in aqueous solutions that needs mathematical expressions. The concept of an electrolytic cell in Grade 12 also does not have concepts that require the use of mathematical expressions. Looking at the other three modes of representations (diagrams, chemical equations and tables) no significant trend can be deduced from the tabulated figures. Hence, on this pedagogical tool of modes of representation, the analysis will be on how individual teachers make use of these modalities in the teaching of scientific knowledge.

According to Table 7.2 above, Mr Johannes Grade 10 had the highest frequency score of 27 from using three modes of representation, which are diagrams, chemical equations, and tables. Mrs Meyer's Grade 11 was second with a frequency of 25 across three modes of representations. However, when one takes all the modes representations into perspective, Mrs Meyer had the highest frequency score of 31 as she used six other modes of representation, which were four pictorial representations, one video, and 1 model. Mrs Ndebele is the only teacher who used all four primary modes of representations with a total frequency score of 24 and was third among the six teachers.

The Grade 12 teachers, Mr Masutha and Mrs Meyer, had a total frequency score of 17, and all of them did not use any mathematical expressions as a mode of representation. Mr Zulu had a frequency score of 11 from two modes of representation, which were chemical equations and tables. The teachers were able to include different modes of representation in the teaching albeit with varying frequencies, which did not have a particular trend within and across grades. Figure 7.1 below shows a graphical representation of how each teacher used each of the four primary modalities.

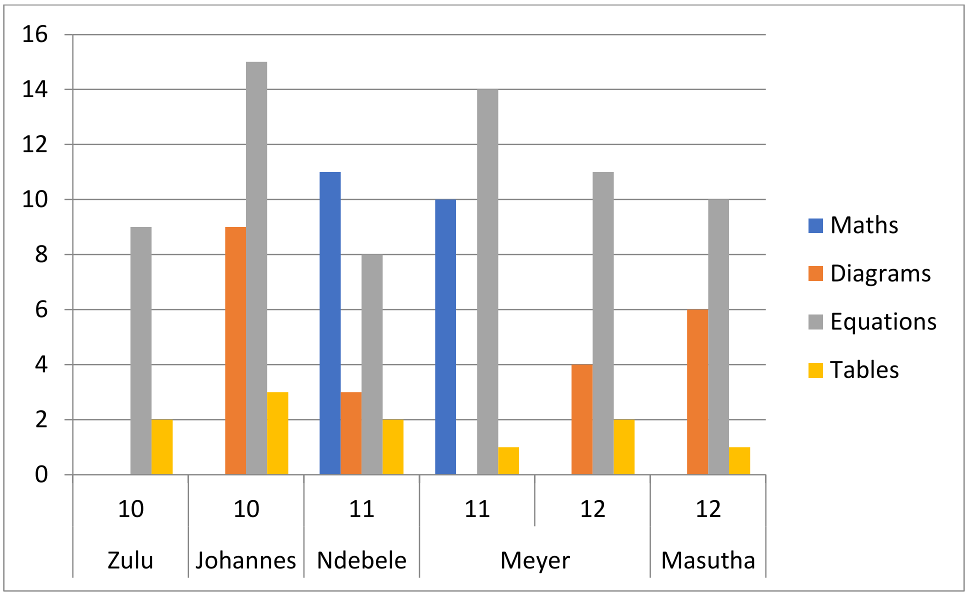


Figure 7.1: Graphical representation of the four significant modalities

All the teachers used chemical equations in their teaching of the three different topics across the grades. The topics included chemical reactions, and teachers had to use chemical equations to illustrate the formation of products from the reacting reactants. The teachers who gave several reactions during their teaching were compelled to show their illustrations through the use of chemical equations.

Also, the teachers who used a few experimental demonstrations had to illustrate each reaction with the use of a chemical equation, whether symbolic or in words. In most cases, they used both words and symbolic representation. Mr Johannes had some experimental demonstrations in the teaching of reactions in aqueous solution and had to show learners chemical equation representations for each experiment that was done. As a result, he had a high-frequency score of 15, which was six times more than that of his Grade 10 counterpart, Mr Zulu. Mr Johannes' score was even higher than that of Mr Masutha, Mrs Ndebele and Mrs Meyer. Mrs Meyer, in Grade 11, did not do many experiments. Instead, she gave several reactions examples that had simultaneous processes of oxidation and reduction more than her counterpart, Mrs Ndebele, with a significant difference of a frequency score of 6. Mr Masutha and Mrs Meyer's Grade 12 lesson presentations had comparable modes of chemical equations representations of 10 and 11, respectively.

The use of tables was the other mode of representation that was used by all five teachers across the six classes from Grade 10 to 12. However, the frequency score was small with an average score of 1.8, with the highest and lowest frequency scores of 3 and 1, respectively. Four teachers used illustrations in the form of diagrams. Mr Zulu of Grade 10 and Mrs Meyer of Grade 11 did not use any type of drawing. Mr Johannes (Grade 10) had the highest score of nine followed by Mr Masutha (Grade 12) with a frequency score of 6. Mrs Ndebele of Grade 10 and Mrs Meyer of Grade 12 managed lowest frequency scores of 3 and 4, respectively. Mathematical expressions were only done by two Grade 11 teachers on the concept of oxidation reactions under the topic of redox reactions, as discussed above.

The use of a mode of representation depended upon the demands of a specific topic or concepts as well as the needs of the curriculum. In the three topics understudy in this research, no graphical mode of representation was used since all concepts did not have a set of results that required the use of a graph. On the topic of electrolysis, learners can be subjected to the calculations of the anode and cathode electrode product ratios, that is the rate of electrolysis and the amount of product formed at each electrode. The latter concept of the amount of product can be linked to the mole ratio that is covered by Chemical Change in Grade 11.

The former concept of rate of electrolysis can be connected to electric current again covered in Grade 11 under the Physics component. However, the CAPS curriculum is silent on this mathematical concept under electrolysis, bringing the aspect of the spiral nature of the curriculum in question as discussed in chapter 4. The inclusion of other modalities in the teaching and learning process depends on the teacher's resourcefulness around that particular concept. The results of this thesis reveal that some teachers used specific modes of representations more than others and some teachers never used the modes at all.

During the interviews, teachers were asked why they preferred to use other modes of representations over others or why they were not using different modalities. There were two noteworthy responses from the teacher's responses, namely, lack of time to use such modalities in the classroom (Mr Zulu and Mrs Ndebele) and lack of school resources, for example, scientific equipment and chemicals (Mr Johannes).

Mrs Meyer and Mr Masutha indicated that the use of such modes of representations was quite valuable in the teaching of chemistry and one has to find time to prepare and use them for an improved understanding of the subject. They endeavoured in all the classes to use them. Surprisingly, Mr Johannes was in the school, which did not have resources such as laptops, data projectors and smart boards, but he managed to do well in the use of diagrams which he was drawing on the board and the use of chemical equations.

Although some modes of representation such as chemical equations do not require any resources except adequate preparation, they were not fully utilised by other teachers. Mr Zulu and Mrs Ndebele could have used modes of chemical equations more, but they were the least with frequency scores of eight and nine, respectively. As for Mrs Ndebele, she had the smartboard with all videos and pictures already preloaded for her but could not make full use of the technology. When the teacher was asked why she was not utilising the technology at her disposal, she lamented about the lack of skills to use the smartboards as they did not receive adequate training and the technicians who were trained also find the technology challenging to use. I witnessed Mrs Ndebele struggling with the smartboard during the first and second classes of Mrs Ndebele. A total of seven minutes was wasted when she was trying to figure out how to switch from an interactive whiteboard to playing videos. On both occasions, when the teacher wanted to switch between these two functions, she could not get the icon to play the video and sometimes learners would help her. When everyone in the class had failed, a learner was sent to call the technician from his office who came and struggled with technology as well.

The use of modes of representation is not only a matter of the teacher's resourcefulness, but it is a skill that a teacher has to acquire through constant use and understanding of the conceptual demands of the topic. McDermott and Hand (2013) identify four skills teachers should possess for the development of multimodal competency. Such skills include suitable approaches for integrating verbal or text with different modes of representation, use of different modes of representations from other sources that can be used as models, in-depth knowledge of the concepts of science under study, and the audience wrote to and the rhetorical requirements of the assignment. McDermott and Hand (2013, p. 240) noted that "until all these skills are realised, effective translation, and ultimately more conceptual understanding, may not materialise”. Therefore, for teaching for conceptual understanding to be achieved in the schools, teachers should be adequately trained to acquire the multimodal integrational skills in the teaching of science. Now a case by case analysis to scrutinise how each teacher linked the modes of representation they used in their various lesson presentation will be done. The question that arises is: how useful was the use of this multimodal representation in the conceptual understanding of reactions in aqueous solutions, redox reactions and electrolytic cells?

7.1.1 Case by case analysis for the link-making of multimodal representations

Mr Zulu Grade 10

As shown in Table 7-1, Mr Zulu only managed to integrate two modes of representations, which were chemical equations and tables. In the first lesson, he only used three modes of representations, which were two episodes of chemical equations and a solubility table. Mr Zulu successfully used the table of solubilities by explaining to learners how each rule could be used to determine whether a reaction will form a precipitate or not. The solubility rules were used as guidelines to predict the formation of precipitates (solids). To make sure that learner comprehended the solubility rules the teacher had a class discussion on how to use the table to determine the solubility of specific compounds. Learners were then given class work which they discussed in groups.

The excerpt below shows how the teacher expertly used the solubility rules to help learners predict the formation of a precipitate.

Turn	*Speaker*	*Transcription*
17	*Zulu*	*Consider the following class work, which of the following compounds are insoluble in water. Let us have many, but I will do the first two with you, calcium chloride and magnesium chloride….* *Let us start with calcium chloride, I go to my table, the first rule it’s about nitrates, the second rule does not involve chlorides, but the third rule is about chlorides now. Do you see that*
18	*Class*	*Yes*
19	*Zulu*	*The rule says all chlorides, bromides and iodides are soluble…. Let us look at the exceptions to this rule. Except those of silver, lead and mercury, so that makes calcium what?*
20	*Thato*	*Soluble*

21 Zulu Correct, let's do Magnesium hydroxide, there should be a statement that has to do with hydroxide is that so?
22 Dennis The last one
23 Zulu It says all metal hydroxides are insoluble except those in group 1 and 2. In which group is magnesium?
24 Keketso Group 2
25 Zulu Yes, group two of the periodic table, so that makes it what?
26 Dakalo Magnesium hydroxide is soluble.

The teacher showed learners how to use the table to predict the solubility of compounds step by step. After that, the teacher led a class discussion, where learners were required to draw their answers from the solubility table. Learners successfully followed the teacher's instructions and went on to answer 10 more questions in their groups without a problem. The teacher used the mode of representation (table) to teach the abstract concept of solubilities, which enabled learners to work out complicated problems in groups through social engagement.

The next mode of representation discussed here is the use of chemical equations to explain the general phenomena of dissolution and precipitation reactions by Mr Zulu. Figure 7.2 below shows how the teacher used chemical equations as the mode of representation.

(a) (b)

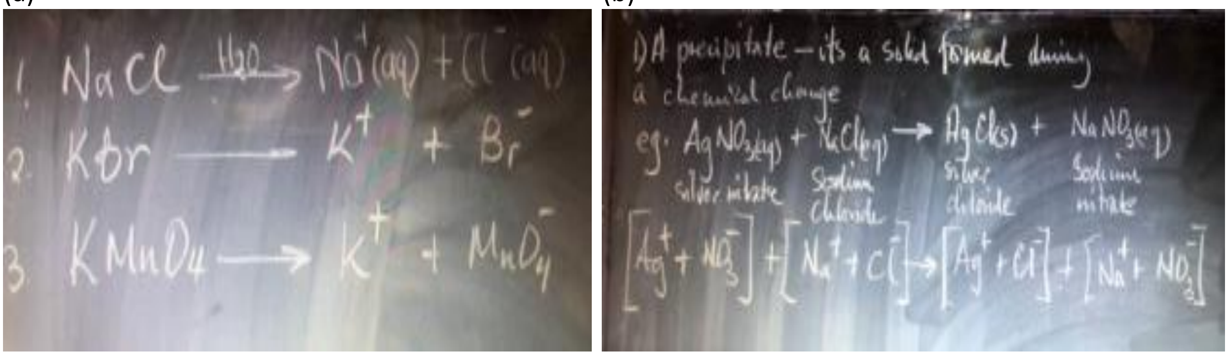


Figure 7.2: Mr. Zulu's chemical equations representations

The diagram in Figure 7.2 (a), was a chemical equation representation for dissolution reactions of different salts. The teacher wrote the reactants and asked learners to complete the equations by writing the products formed after dissolution. The products of the first chemical equation, the dissolution of sodium chloride (salt) was written by a learner known as Sessi who included water and state symbols which the teacher had omitted. The learner did not explain or utter a word. She just wrote her answers on the board then the teacher took over as indicated in the following extract.

Turn	*Speaker*	*Translation*
3	*Zulu*	*Right, first one – Sodium chloride.* *When sodium dissociates in ions, it will form a sodium positive ion and chloride negative ion. Correct?*
4	*Class*	*Yes*
5	*Zulu*	*Moreover, we did this when we were looking at bonding in term 1, where electrons are transferred from the sodium metal atom to the chlorine non-metal atom.* *Now because of time, I am going to give you the memo for the other two is that so.* *The story is the same which means here my potassium plus one and bromide negative one. This one was going to give you a challenge ne because there are three atoms now. But when you take the metal potassium and whatever remains and then it becomes negative correct.*

The verbal explanations were qualified by the chemical equations which helped the teacher explain what happened during the dissolution of salts in water (solvent). The teacher was filling in the answers as he was speaking and did not include the water as the learner had done as well as the state symbols. However, it is the small omissions such as incomplete equations, which normally cause some confusion and misconceptions in learners. As was observed in Mr Zulu's class, some learners were not including states of matter in their equations.

The teacher never emphasised the states of matter much, but in some cases, he included them as seen in Figure 7-2 (b) above. The second picture exhibit how the teacher represented the formation of a precipitate in the reaction between silver nitrate and sodium chloride. It is the representation of the full ionic equation, which is of concern here. All the dissociated ions were shown in the equation appropriately except for the solid silver chloride. Had the teacher included the states of matter, he was not going to split the silver chloride. Writing silver chloride compound as separate ions [Ag^+ + Cl^-] means that it dissociates in the water of which the compound is insoluble in water.

Although the teacher was correctly explaining that silver chloride is insoluble in water verbally, his representations were inconsistent with his explanation. The correct way of writing the full ionic chemical equations is shown below.

$$Ag^+_{(aq)} + NO^-_{3(aq)} + Na^+_{(aq)} + Cl^-_{(aq)} \rightarrow AgCl_{(s)} + Na^+_{(aq)} + NO^-_{3(aq)}$$

Representation is meant to be a tool that augments the verbal explanation and once the two do not correlate meaningful learning is adversely hampered (Tsui & Treagust, 2013). In precipitation reactions, chemical equations depict the relationship between reacting compounds and the product regarding solubility, which is seen through a change in states of matter. Failing to emphasise the states of matter would not drive home the value chemical representations brings as far as understanding of precipitation reactions is concerned. Unfortunately, the above full ionic equation was the only example that was given by the teacher in all the three lessons observed. Learners were also not taught about how to get the net ionic equation of the reaction through the elimination of spectator ions (species that appear unchanged after the reaction) in the final net equation.

Nonetheless, learners were able to move between the word explanations on the formation of a precipitate and chemical equation as was observed in lesson 3. Learners were given homework of predicting end products of precipitation reactions in the form of chemical equations see Figure 7.3 below.

(a) (b) (c)

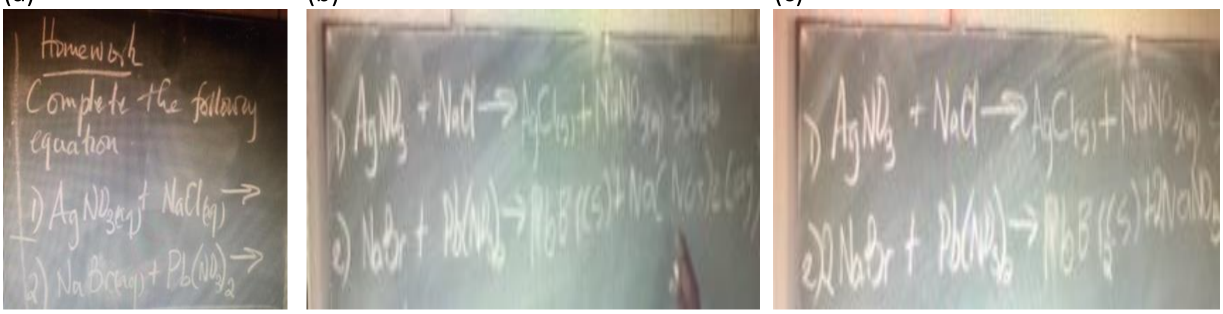


Figure 7.3: Representations of precipitation of halides in Lesson 3

Figure 7.3 (a) above shows the homework that was given by the teacher at the end of the second lesson of two precipitation reactions with all state symbols written on each reactant. At the beginning of lesson 3, the teacher rewrote the reactants of the two equations without state symbols (Figure 7.3 (b)). However, two learners who were chosen to write the products of the two equations managed to write all products with state symbols. Learners were writing the chemical equations with state symbols consistently because the teacher emphasised the writing of state of matter during checking of homework at the beginning of the lesson when he realised that most learners were not writing them down. The learner who wrote products of the second equation (Figure 7.3 (b) could not write a balanced chemical equation although the state symbols were correct. The teacher had to help learners to balance the equation diagram 7.2 (c), by reminding them how to balance equations as they did in term one.

Tsui and Treagust (2013) argue that multimodal representations are more useful in displaying a diversity of information and problem-solving proficiency hinge on the learner's range of multiple representations of the same domain. If Mr Zulu had included more multiple modes of representations, his lessons were going to support meaningful learning rigorously.

Mr Johannes Grade 10

Mr Johannes used three modes of representation: diagrams, tables and chemical equations. He used a total of 27 modes of representations, which comprised of three tables, 15 chemical equations and 9, as shown in Table 7.2 above. Mr Johannes used four groups and two pair episodes for class work. In the group and pair class work, learners were drawing diagrams and tables instead of the teacher doing everything for the learners. Nixon, Smith, and Wimmer (2015) posit that learners should not be left to decipher the meaning of the modes of representation on their own. Instead, the learner should be taught how to use and interpret each mode through practice in science classrooms. In his lesson presentations, Mr Johannes tried to involve and scaffold where he could to educate learners on how to use the three modes of representation, and he used in his science class.

He used three tables of data representation. The three were a table of solubilities, a table of results that compared halide precipitation reactions, and a table of results to classify whether a precipitation reaction takes place or not. In the teaching of solubility, Mr Johannes used the three modes of representation, namely, words, table, and chemical equations in teaching for understanding how a precipitation reaction takes place. He used the reaction of silver nitrate, and sodium chloride and learners were taught how to use the table to predict whether a particular compound will be precipitated or not in the aqueous reactions.

The episode below shows Mr Johannes presenting multimodalities of representation in Lesson 1. The class was discussing the precipitation reaction of the formation of silver chloride. The teacher first reminded learners about the solubility table and dissolution reactions before giving learners a task to predict what will happen between sodium chloride and silver nitrate see extract below.

Turn	*Speaker*	*Transcription*
33	*Johannes*	*In your class workbook, I want you to draw a diagram or diagrams that show what will become or what will be the result when you react silver nitrate with sodium chloride. I want to draw a diagram that shows what is likely to happen when you mix the two reactants, but you discuss in groups of 5.* *The seating arrangement was conducive to a group discussion. The group closer to the video camera had found learners, and they started the discussion on the task.*
41	*Beauty*	*We need to follow the rules, isn't it?*
42	*Betty*	*Yeah*
43	*Belinda*	*I think it is going to be a solid*
44	*Belinda*	*Yeah it is going to be solid*
45	*Bianca*	*But then how are we going to do it*
46	*Betty*	*We must show by drawing a diagram*
47	*Bianca*	*In our books*
48	*Betty*	*Silver chloride is going to be solid, and this one is going to be ….*
49	*Beauty*	*Yeah, this one it is going to be solid*
50	*Belinda*	*Isn't is it going to be … I see you exchange here, and we shall have chloride*
51	*Betty*	*Then we have silver chloride*
52	*Bianca*	*We have silver nitrate*
53	*Belinda*	*No, it is silver chloride. Yes, it's a silver chloride*
54	*Betty*	*We have silver chloride and sodium nitrate, this one goes there and this one here*
55	*Beauty*	*This one is a solid*
56	*Belinda*	*Yeah*
57	*Beauty*	*And this one also a solid*
58	*Belinda*	*No*
59	*Beauty*	*Yes*
60	*Belinda*	*Let us just check the which number in the rules of solubilities*
61	*Betty*	*They say all nitrates are soluble*

Before they drew the diagram, this group wanted to know what was going to be formed first and they were entangled in an argument whether sodium nitrate was a solid or not. They had to refer to the table of solubilities where they discovered that sodium nitrate is soluble and does not form a solid. It took learners themselves to convince each other without the teachers' help to ascertain from the table that only silver chloride would be a precipitate. The mode of words had failed to convince Beauty of the nature of sodium nitrate in aqueous solution, and the table had to be used to make her understand. Learners on their own could work interchangeably between words and the table and were ready to embed on another mode of presentation, which was drawing a diagram of the reaction. Learners were using their imaginations, as the teacher had not yet performed the experiment. Figure 7.4 below shows two diagrams that were produced by learners.

(a) (b)

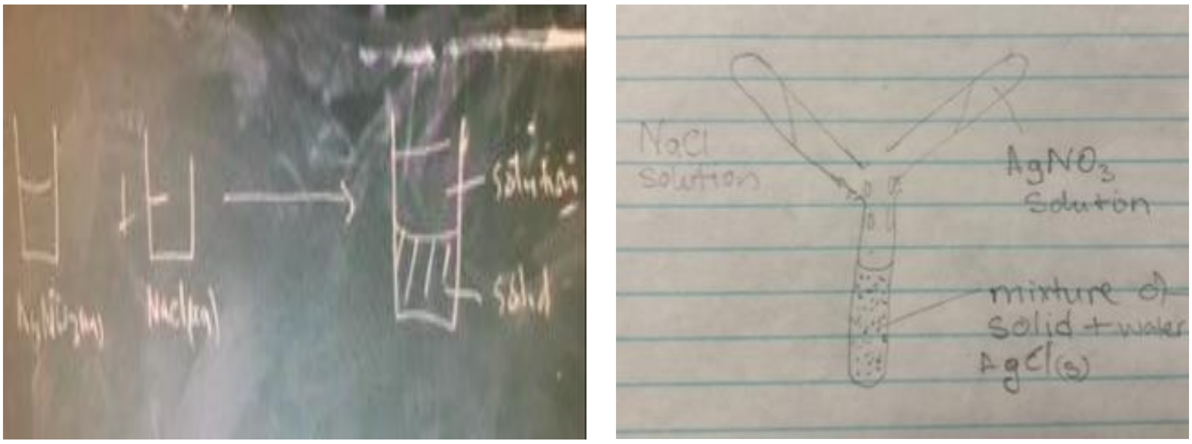


Figure 7.4: Diagrammatical representation of precipitation reaction

The two diagrams shown above came up to be of importance, in the teaching and learning process. Figure 7.4 (a) was drawn by one group, but the teacher is the one who drew it on the board instead of asking one of the group members to come up to the board and draw it. The second diagram (Figure 7.4 (b)) was drawn by a group close to the camera, and I captured the picture as a screen shot. This group did not volunteer to give input when the teacher asked the class about their diagrams. However, after the teacher drew the diagram represented in Figure 7.4 (b) on the board, the group members were happy and gave each other 'high fives' (a way of congratulating each other) in satisfaction. The learners correctly imagined two colourless solutions in test tubes being mixed in another test tube where a mixture of minute particles and water were observed. Learners failed to recognise that sodium nitrate would also be present in the final mixture. However, they correctly predicted the formation of a silver chloride precipitate.

The teacher managed to move learners from a verbal explanation of the formation of precipitate to a visual perspective in the form of a diagram. Learners had to transform their imaginary physical phenomena into the diagrammatical representation to explain what will be happening in the chemical processes. Such flexibility of movement from one mode to the other deepens the understanding of the concept by the learner. This was done in a social context where learners negotiated and agreed on facts of science guided by the table of solubilities that gave an authoritative scientific view. The use of such specific representation systems and tools permits learners to express their thoughtfulness of invisible chemical entities and processes and are similar to what scientist use in real life (Kozma, Chin, Russell, & Marx, 2000). Lemke (1998, p. 250) argues that the "… verbal discourse of the classroom itself is often not fully comprehensible without co-reference to visual, gestural, or mathematical representations". Therefore, the use of multimodalities in the classroom ensures meaningful learning as learners display evidence of their understanding of the scientific concepts through the use of representational tools.

At this point of the lesson, learners had been exposed to three modes of representation which were verbal discourse, use of tabulated information and prediction of scientific phenomena in diagrammatic format. After the drawing of the diagram, Mr Johannes did an experimental demonstration of the silver chloride precipitation reactions. Learners already knew the outcome, and the experiment was a confirmation of what they had already conceptualised. However, the change of colour amused learners and their interest and involvement were increased. Mr Johannes took learners to another level of matching verbal questions with a diagrammatic representation of what was happening at the microscopic level after the experiment. The details of how the approach unveiled will be covered in the next section which looks at making links between different scales and levels of explanation. Nevertheless, Mr Johannes also used chemical equations as a tool to decipher how ion exchange takes place between silver nitrate and sodium chloride solutions.

The same reaction in an aqueous solution of silver chloride precipitation was used to illustrate the writing of full chemical equations, full ionic equations and net ionic equations. The teacher used the authoritative scientific discourse to enlighten learners of how to write the mentioned set of equations, as illustrated in Figure 7.5 below.

(a) (b)

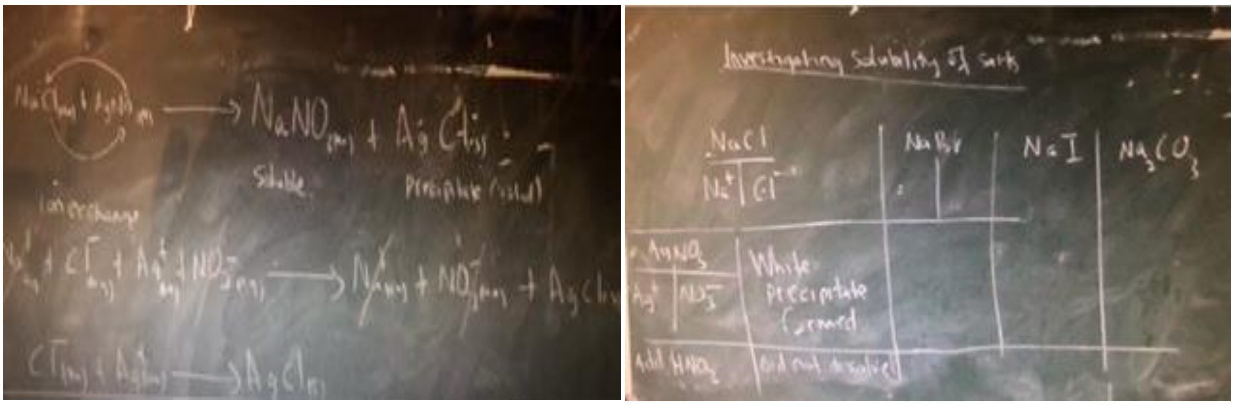


Figure 7.5: Use of ionic equation and a summary table of halide salts

The teacher wrote the full chemical equation and explained, step by step, how ion exchange takes place once the solutions were in one test-tube (Figure 7.5 (a)). Spectator ions were eliminated to come up with a net ionic chemical equation. In the second lesson, the teacher did more experiments to test for halides, and the reaction of silver nitrate became an example for the learners to answer questions on the reactions of silver nitrates and halide salts. One of the activities was on completing a table of results, which enabled learners to summarise all the experimental demonstrations of reactions of halides done by the teacher.

Figure 7.5 (b) shows how the teacher designed the table of results to summarise the halide precipitation reactions. In the first row, learners were to identify the ions of the halide salt in aqueous solution. The second row required learners to identify the colour of precipitate formed and the last row asked for nature of a reaction between the precipitate and the nitric acid, that is whether the precipitate formed dissolved or not. Subsequently, learners were tasked to write their inferences and three chemical equations for each reaction, which were full chemical equations, full ionic and net ionic equations.

Mr Johannes exposed learners to a variety of modes of representations which he systematically planned. Learners were introduced to verbal scientific explanations of dissolution and precipitation reactions, followed by a tabulated representation of scientific views on how predictions of precipitation reactions can be made. The next step involved learners predicting results of a precipitation reaction by drawing a diagram that showed microscopic representation. Chemical equations and table of summary of results concluded the teacher's representations.

All these seven representations were instituted to explain the concept of precipitation reactions in aqueous solution. The combined use of two or more multimodalities is encouraged to efficiently communicate a single meaningful and complex science concept to the learners (Lemke, 1998; McDermott & Hand, 2013). The use of these multimodalities by Mr Johannes proved to useful in explaining different scientific concepts. The verbal mode was used to explain the scientific point of view of precipitation reactions; the table was used to help learners draw required scientific concepts to solve a problem. The imaginative diagrams were used to invoke learners' critical thinking of what is to be expected. The microscopic diagrams were used to explain the nature of invisible chemistry. Chemical equations were to show how ion exchange takes place in aqueous solutions, and the summary table was to help learners conceptualise the whole process of precipitation reactions. Mr Johannes followed this sequence when he was teaching about other reactions in aqueous solutions such as redox reactions and acids and bases in lesson 2 and 3. Let us turn now to other grades and analyse the nature of the use of these multimodalities by other teachers.

Ndebele Grade 11

The major topic in Grade 11 was redox reactions. However, both Mrs Ndebele and Mrs Meyer had to discuss the concept of oxidation numbers first. The notion of oxidation numbers was a pre-requisite concept to the understanding of redox reactions. Hence, it was of importance for learners to understand the assigning of oxidation numbers to elements within molecules and compounds.

Five different Modes of representation were used by Mrs Ndebele in teaching the concepts of oxidation numbers and redox reactions, which consisted of videos (2), tables (2), chemical equations (8), diagrams (3) and mathematical equations (11).

Just like in the Grade 10 topic of precipitation reactions, Mrs Ndebele began with a verbal explanation of the concept of oxidation numbers using a set of scientific rules. The topic of oxidation numbers was new to Grade 11 learners; hence, the teacher had to use a set of scientific rules and the periodic table in teaching learners to assign oxidation numbers to elements, molecules and compounds. The first lesson was dedicated to the understanding of each rule through explanations and working on examples. The teacher then showed learners a video, which summarised the rules and gave further examples of how to solve problems of oxidation numbers of simple and complex compounds. Subsequently, learners were given a class work of solving problems of simple molecules, which was done in groups of 4. Each group then chose a learner to present their solution on the smartboard. The first lesson ended with homework of simple molecules. The second lesson began with the discussion of the homework, and individual learners volunteered to present their solutions to the whole class. Then the teacher gave more class work for learners to solve problems of more complex molecules and compounds. The last lesson was on redox reactions where learners applied the knowledge of oxidation numbers to determine the two processes of reduction and oxidation.

In the first lesson, the teacher used four modes of representation, which were rules of assigning oxidation numbers, the periodic table, mathematical expressions and a video. In solving a problem of assigning oxidation numbers to each element in a compound, learners were supposed to derive their reasoning from the rules and the periodic table and use mathematical expressions to calculate the oxidation state of the element that was not covered by the rules. The method used by the teacher in solving problems was the same method used by the video presenter. Interestingly, during group presentations, one learner used a different method from what the teacher and the video had presented, as shown in Figure 7.6 below.

(a) (b)

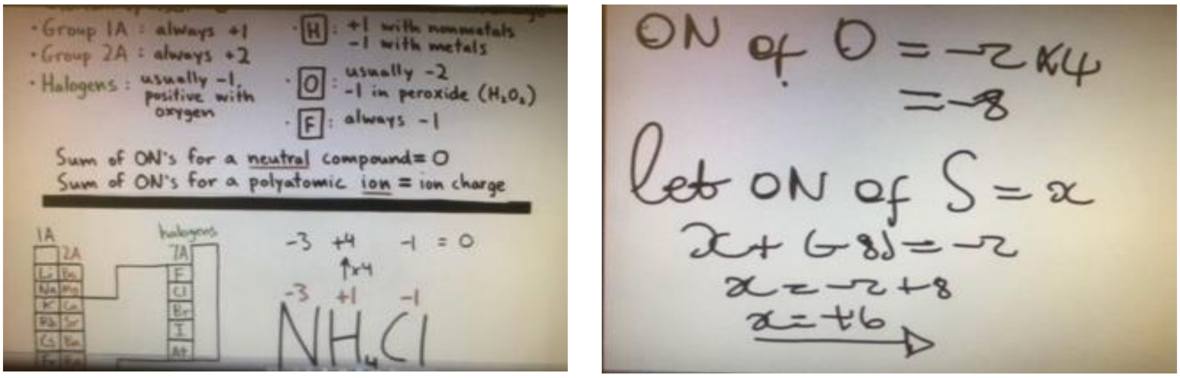


Figure 7.6: Comparison of two mathematical expressions to solve oxidation number problems

Diagram 7.6 (a) shows what was presented in the video; the part above the thick line gives a summary of rules which the presenter always referred to when solving problems. The portion below the bold line had a periodic table, which was also used regularly to identify groups of different elements. The right side of the bottom part was where the presenter did calculations of the oxidation numbers.

Figure 7.6 (a) shows that the presenter used three rules, namely; the sum of oxidation numbers (ON) of a neutral compound is zero, halogens in group seven (from the periodic table) has an ON of -1 and hydrogen (H) bonded with non-metals have an ON of +1. He calculated the ON of the nitrogen atom. The right-hand side of his mathematical expression was then zero since the compound was neutral and had to work out the left-hand side to be zero as well. ON of H was multiplied by four because there are four atoms of H, giving a total number of +4. On the same side, the chlorine atom had an ON of -1, adding the two numbers together they gave +3. Hence the ON of Nitrogen was -3 so that left-hand side was equal to zero.

In contrast to the presenter's and the teacher's methods, Figure 7.6 (b) shows how a learner derived a mathematical expression from calculating the ON of an ionic molecule of SO_4^{-2} (sulphate ion). Without any verbal interactions the learner first calculated ON of oxygen using the rule that in all other compounds which are not peroxides oxygen atom has an ON of -2. Since there were four oxygen atoms in the sulphate ion -8 was the total ON all the oxygen atoms. The learner then assigned sulphur an oxidation state of *x* (the known). Using the calculated sum of ON of oxygen, the learner then derived a mathematical equation where he had to solve for *x.* The left-hand side was then equated to the charge of the ion, according to the rule of polyatomic charged ions. The method of using a mathematical expression was frequently used by several learners especially in the second lesson when individual learners were presenting their homework on the board. Learners' presentations showed that they understood Zamo's method than what was presented by the teacher and the video presenter. The teacher had to refer to this method during her explanations in the first lesson. In the excerpt below, the teacher was explaining how to find the ON of carbon (C) in carbonate ion CO_3^{-2}.

Turn	*Speaker*	*Transcription*
71	*Ndebele*	*Let's go back; some are still struggling ... How did they get the +4 for the ON of C.? What is happening we got* CO_3^{2-}*ne and we are saying* CO_3^{2-} *we know ON of the oxygen ne, … So how many oxygens do we have, Sicelo?*
72	*Sicelo*	*3*
73	*Ndebele*	*We have three So we saying each has an ON of -2 so it will be -2x3 and it gives us -6. Do we know ON for C?*
74	*Class*	*NO*
75	*Ndebele*	*C is an unknown. That is why Zamo had to place an x, we want to find ON of C. So, we place an x but already we know the ON of* CO_3^{2-} *ne, what is it, it is?*
76	*Class*	*It is -2*
77	*Ndebele*	*So, its x + (-6) = -2. Then here we a making x the subject of the formula. That will be the ON of C.*

Learners were having problems in solving polyatomic charged ions, and the teacher had to abandon her formula and adopted Zamo's approach. In her explanation, Mrs Ndebele acknowledged Zamo as the author of the formula, which was a huge motivation. The approach was used by several learners who presented on the board. Out of seven presenters, five used the mathematical expression method as derived by Zamo, see Figure 7.7 below.

(a) (b)

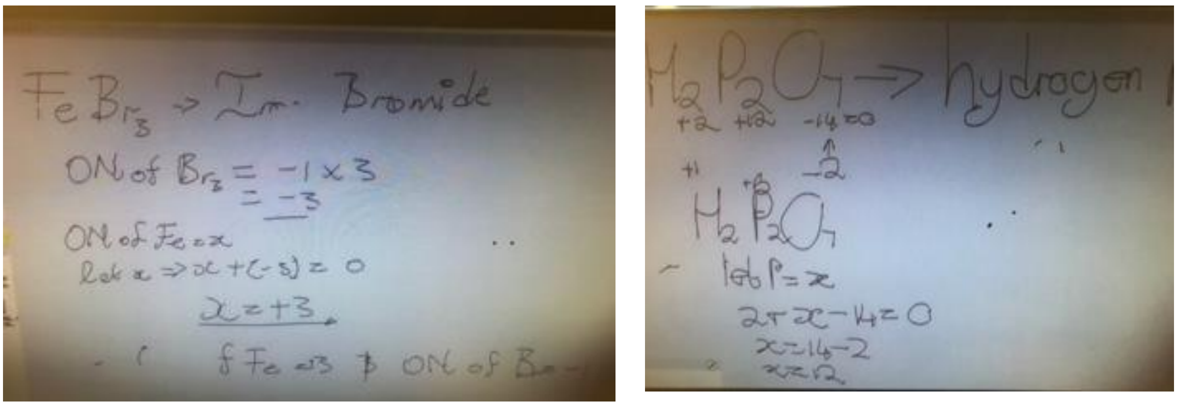


Figure 7.7: Problem-solving of oxidation numbers by learners

After writing their answers on the smartboard, learners were asked by the teacher to explain how they got to the answer. Figure 7.7 (a) was done by Zakes, who spoke louder and could be captured by the video camera. Only the teacher had the audio recorder strapped on her and learners cold only be captured from the video camera if they were loud enough. The excerpt below is a narration of Zakes' presentation.

Turn	*Speaker*	*Transcription*
30	*Zakes*	*This is* $FeBr_3$ *which is iron bromide. Basically, Br in group seven has an ON of -1according to the rules. Since they are three Br atoms, we are going to multiply by 3. Hence, we are saying -1, which is the oxidation number of Br multiple by 3 atoms it gives us negative 3. Then we let oxidation number of Fe which is iron to be x since it the one we are looking for. Hence, we say x + (-3) = 0 we transpose, and obviously, our x will be positive 3. In conclusion, we say an oxidation number of ions is equal to positive 3, and the oxidation number of bromine is equal to a negative one.*

Zakes used three multimodal representations, that is, the periodic table, rules, and mathematical expressions to solve the problem of oxidation numbers. He used the modes of representations in the same manner as the knowledgeable others (Video Presenter, Mrs Ndebele and Zamo). Zakes' reasoning and quoting of scientific rules to justify his action showed that he had a conceptual understanding of oxidation numbers. From the presentations made, the teacher is not the only expert in the classroom. Learners can use their conceptual understanding of mathematics, which is another different learning area, to meaningfully explain the scientific conceptual phenomena. Such link-making by the learner and not the teacher exhibits a total conceptual understanding of the scientific view and is evident in the process of knowledge building by multimodalities. The power of multimode representation was pivotal in enabling the teacher to explain redox reactions in Lesson 3 meaningfully.

Unlike in lessons 1 and 2, where three modes of representations were used, in lesson 3, Mrs Ndebele used five modes, which were, oxidation number rules, video, diagrams, chemical equations and a table to summarise the main points of oxidation and reduction processes. The video was used to show learners the microscopic movement of electrons from one compound to the other in a reaction. How the video became useful in explaining the redox reactions will be done in the next section. The narratives of the other modes of representation are captured in Figure 7.8 and the excerpt that follows.

(a) (b)

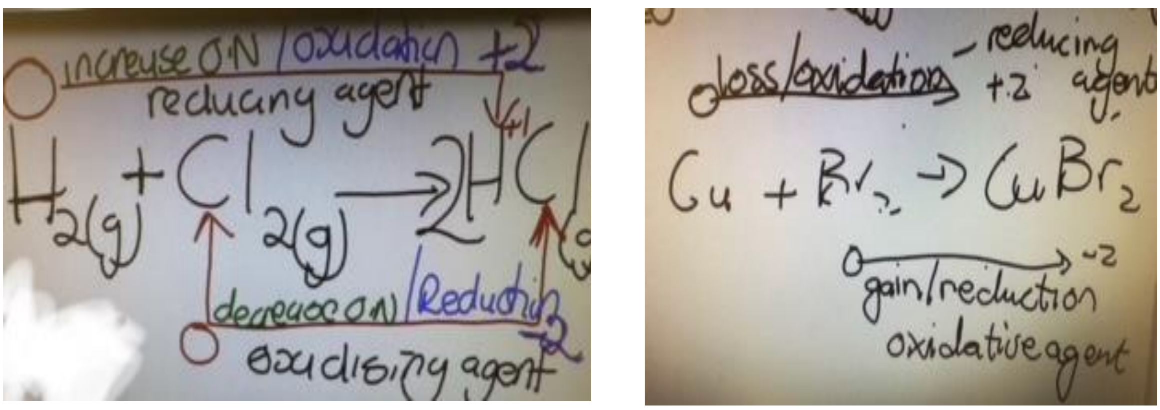


Figure 7.8: The use of Multimodalities by both teacher and learners

Figure 7.8 (a) above was the teacher's presentation when she was explaining how learners can identify reduction and oxidation processes on a chemical equation. Mrs Ndebele used the rules of oxidation numbers to determine the ON of each species in the chemical equation. Using arrows, Mrs Ndebele indicated how H_2 gas has been oxidised from ON of zero to ON of +1 and how Cl_2 gas was reduced from ON of 0 to ON of -1. Arrows are part of modes of representation that are used in the same manner as diagrams. Hence, the teacher diagrammatically showed learners the movement of electrons during the gain and loss of electrons. Once again, the teacher gave learners class work that was discussed in groups and learners then presented their answers to the rest of the class. Figure 7.8 (b), was presented by Kennedy; his explanation is captured on the extract below.

Turn	*Speaker*	*Translation*
23	*Kennedy*	*According to rule number one of finding ONs. I realised that Cu was zero because of its one element. From reactants to the products Cu change from zero to, ok well, I did not know the oxidation number of Cu in $CuBr_2$, so I left it alone. I came back to bromide. Bromide because it is a diatomic molecule its oxidation number is zero and I do know that*

bromine is a halogen, therefore it has an oxidation number of negative one. There are two bromines here meaning negative one is multiplied by 2. I then released that this compound which is the product of this equation had an ON of zero. Meaning if Bromine has a total negative of two, then Cu has an ON of positive 2. I noticed that here there a gain of electrons, therefore, the reduction was taking place and for reduction to take place there was an oxidative agent. Here there was a loss of electrons meaning oxidation took place, and there was a reducing agent that was present

The learner precisely described the phenomenon of redox reaction and used the modes of representation in the way the teacher had used the diagrammatical illustrations, as shown in Figure 7.8 (b) The rules guided the learner to identify species that were oxidised and those that were reduced. The chemical equation was to trace the movement of electrons by identifying species that accepted electrons and those that gain them. It is evident that the more modes of representations are used to explain a scientific phenomenon the more understandable the scientific concepts would be to the learners. Relying on only verbal discourse is likely to make the science concepts look difficult and formidable to conceptualise. Although the literature advocates the use of two or more modalities, in this research context, a minimum of three modes are necessary to meaningfully and adequately explain a scientific phenomenon for conceptual understanding.

Mrs Meyer Grade 11

In her Grade 11 classes, Mrs Meyer used a total of five modes of representation with a total frequency score of 30. She had the highest frequency score than any other teacher in the research. Mrs Meyer used pictures (4), chemical equations (14), mathematical expressions (10), tabulated information (1) and one model structure. Mrs Meyer was teaching the same topic of redox reactions as Mrs Ndebele. Instead of starting with the rules of oxidation numbers as was done by Mrs Ndebele she began her lesson by analysing the atomic structure using a model and defining the processes of reduction and oxidation.

The model was that of an atomic structure that showed the arrangement of electrons in the outer shells and Mrs Meyer pointed out that it is the outer electrons that are involved in a chemical reaction. She explained that the outer electrons are transferred from one element or compound to the other during a chemical reaction.

Although the use of the model as a mode of representation and the linking of it to the electron exchange was relevant, the teacher did not involve learners in the link-making. Learners were supposed to be involved in identifying the position of electrons and nucleus in the model. Unless learners are involved and participate in the link-making and the use of the model it is difficult to ascertain learner understanding. As was mentioned in the preceding chapters, Mrs Meyer's approach involved narrating the scientific view to the learners first and giving learners a chance to apply what she has been teaching by doing class work in groups in the second half of the lesson. However, during the group discussion, which I managed to listen to, no learner engaged with the model. It is not clear to me whether the mode was helpful or not in facilitating meaningful learning on the concept of redox reactions.

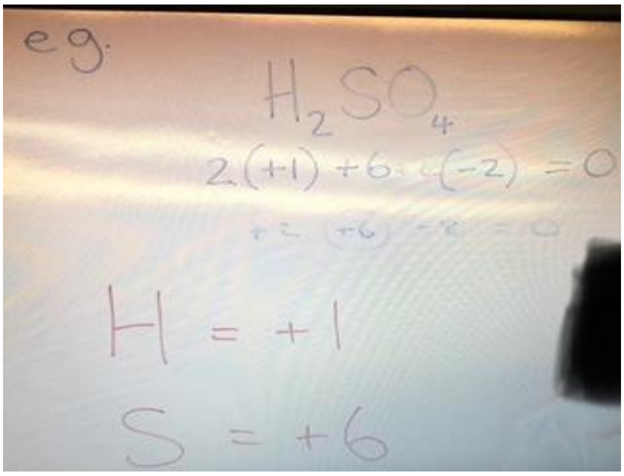
Other than the model and verbal discourse, Mrs Meyer also used pictures in her introduction of redox reactions to the learners. The excerpt below shows how she referred to several pictures in her talk on redox reactions.

Turn	*Speaker*	*Transcription*
19	*Meyer*	*…. We are busy with the redox reactions. In your textbook there, you can see redox reactions. They gave you the little picture there. The one picture is rust; you can see the picture of the train there that is covered with rust. Rusting is a redox reaction. If you look at figure 14.2, you can see that it is a spaceship or rocket. That is being launched into space. It has got all of those fumes and gases that are coming out at the bottom. That is the redox reaction of burning hydrogen gas. That is get burnt; we burn it up in the air we call it an oxidation reaction. It gets oxidised, and something gets reduced. ….* *Now in a redox reaction, this is what happens, here is a transfer of electrons. One of my reactants gives away electrons, and the other one will receive it, then we have two processes that are happening. The one is oxidation, and the other is a reduction, but we need to define these two processes, and they take place together.*

Pictures were used in the same way as that of models, learners were referred to the representations, and the teacher explained the information depicted on those pictures. The teacher did not solicit learner input regarding what they were seeing or what they know about the pictures in question. Mrs Meyer is consistent on her use of this approach as it saves her time to cover the required amount of work in a given lesson. Learners were given ample time to engage with the work during group discussions. At this point, she had used three modes representations in her introduction of redox reactions, which were a model, pictures and verbal discourse (most dominant). However, each representation was explaining a different concept altogether. The model explained the source of electrons that would be exchanged in redox reactions, and pictures gave everyday examples of where we find redox reactions. Other than verbal discourse, Mrs Meyer used one representation to explain a scientific phenomenon which is below the suggested benchmark of representations of two or more modes of representation (Kozma et al., 2000; Lemke, 2005).

After her introduction of redox reactions, Mrs Meyer indicated that for one to know whether an atom or compound has gained or lost the electrons, a concept called oxidation numbers is used. She further defined the term oxidation numbers and gave learners rules that govern the assigning of these numbers to different categories of elements. At this juncture, Mrs Meyer used three more modes of representations, namely, chemical symbols and equations, mathematical expressions and the periodic table. Figure 7.9 shows how mathematical equations were incorporated in determining oxidation numbers of elements.

(a)



(b)

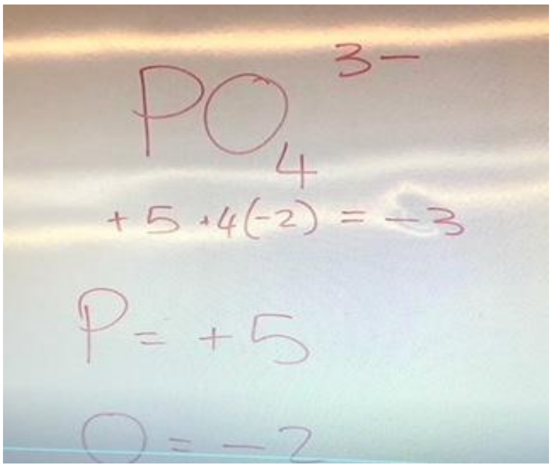
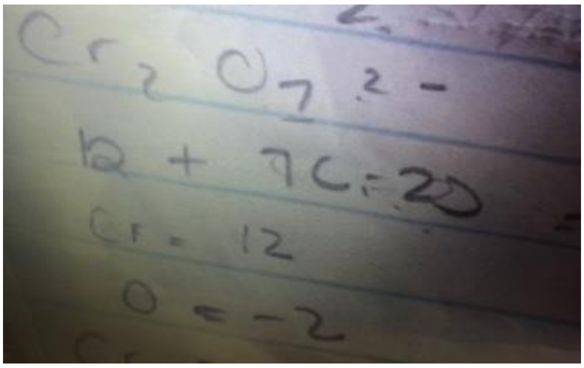


Figure 7.9: Mrs Meyer's use of mathematical expressions

The method used here was the same with what Mrs Ndebele and the video presenter used. Learners were encouraged to determine the overall charge of the compound; if it is neutral, the right-hand side will be zero (Figure 7.9 (a)) and if it is a charge the right-hand side will be equal to the charge of the polyatomic compound (Figure 7.9 (b)). Learners worked the left-hand side so that it equals to the right-hand side. Contrary to Mrs Ndebele’s approach of starting from simple molecules to complex molecules, Mrs Meyer began with complex compounds and polyatomic ions, as indicated in Figure 7.9. The effect of this approach was observed during group discussions where several learners struggled to assign oxidation numbers of complex polyatomic atoms. Figure 7.10 (a) shows how one group failed to get a +6 as oxidation number of chromium in dichromate ion. Their mathematical expression was not clear, but they found the oxidation number of chromium to be 12 instead of +6. Nevertheless, one learner was able to solve the problem, as illustrated in Figure 7.10 (b).

(a)



(b)

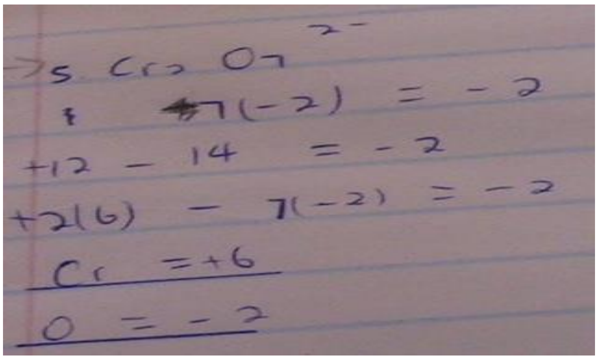


Figure 7.10: Learners' use of mathematical expressions

One learner was able to solve the problem, showing clearly the steps taken to arrive at the oxidation number of +6 for chromium in chromate ion (see Figure 10(b)). The same learner was asked to explain to another group that was struggling to understand the concept. The extract below is part of his explanation, which was different from the working above.

Turn	*Speaker*	*Transcription*
	Linett	*Yooo, I do not understand at all*
	Gloria	*Kikiki, (laughing), So am gonna have to explain again. Ooh my gosh, must I explain this one again*
	Tshidi	*Yeah*
	Gloria	*Aaah, wait, wait (thinking) I need a sum for this for you to understand. Let me explain something simpler, and I will come back to you with this one.*
	Linett	*Ok. Number 3*
	Gloria	*It is CH what*
	Tshidi	*CH 4*
	Gloria	*CH 4, … when you go by the rules, you know that H is given. H is a positive one, right unless the rule states otherwise. Then you know H is positive 4, and you are looking for C and C is not given. So, what you do you are basically solving for x. So, its C H four right and the C is gonna be your x. H here is the positive one you multiply by 4, and you equate to zero because there is no exponential number.*

Fine, I say x plus one multiply by four which is four right, which is equal to zero. I am looking for x, then x is equal to I move four to the other side and it becomes minus 4. Then x is minus for which is my C.

When Gloria came to realise that her formula, which she learned from the teacher, was not being understood she changed it and used a single variable mathematical equation to solve the problem. The following mathematical representation summarises her explanation:

$$x + 4(+1) = 0 \qquad \textit{Equation 7.1}$$

Using Equation 7.1 above, Gloria guided learners until they could solve the chromate ion, which the group did with renewed confidence. However, the teacher was not concerned about how learners calculated the answer; she was only interested in the final assigning of oxidation numbers for each element in a compound. One learner asked the teacher if they have to use the formula with an x or the one without an x and the teacher had this to say;

Meyer *Like I just told Tshidi, I am not gonna look at your sum. I am going to look at the final answer I need to see that each oxygen its minus two if you write four (-2), I am not going to mark it. I only make the final answer.*

Mrs Meyer's refusal to recognise the importance of mathematical expression in finding the oxidation numbers of molecules was failing to understand the impact such mode of representation has on the conceptual understanding of the concept. Due to the lack of proper guided mathematical expression, most learners struggled to come up with an oxidation state of dichromate and chromate ions. Most learners in their groups had to call the teacher to come and re-explain how to find the oxidation number. Mrs Meyer's view of not using mathematical expressions continued in all her remaining two lessons, as illustrated in Figure 7.11 below.

(a) (b)

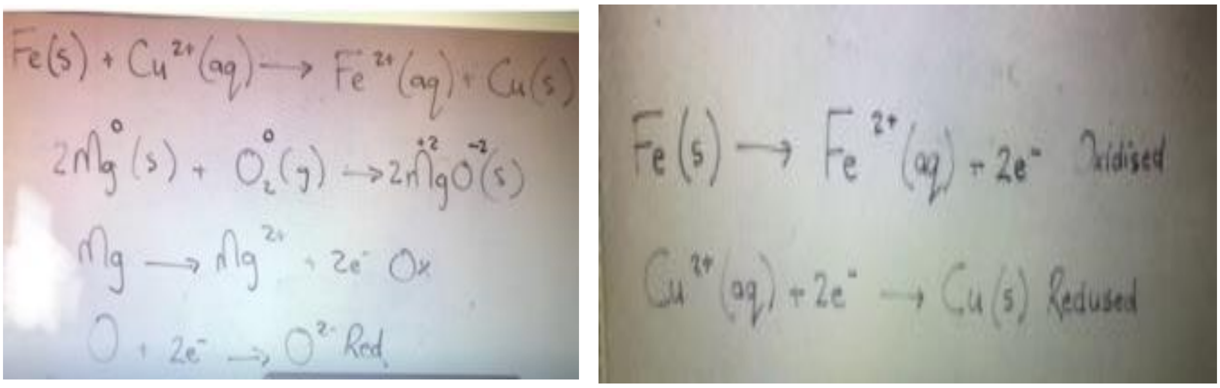


Figure 7.11: teacher's use of chemical equations and mathematical expressions

Figure 7.11 (a) illustrates how Mrs Meyer explained the oxidation and reduction processes. She assigned oxidation numbers to atoms in a compound by inspection. Unlike Mrs Ndebele, she did not use arrows to show learners the species that had been reduced and the ones that have been oxidised. Nonetheless, she adopted a different approach of writing half reactions which indicated the two processes of redox reactions. The half reactions indicated the specific species that either accepted or gained electrons. Other than the verbal discourse used by Mrs Meyer, she also used two modes of representations, which were, chemical equations and mathematical equations. Learners used the same two multimodalities as the teacher. It is clear from my findings that learners use modes of representations that their teachers use.

Mrs Meyer Grade 12

Mrs Meyer continued with the way she taught the Grade 11 classes of first explaining the scientific conceptual view with very minimum engagement with the learners. The interaction with learners was usually at the beginning of a lesson when she brainstormed on the topic, soliciting for previous knowledge and connecting that content to the new topic under discussion. After that, she explained the concepts with the minimum class discussion if any. With the Grade 12 class Mrs Meyer was teaching the concept of electrolytic cells and managed to use five modes of representations, as shown in Table 7.1 above. She used one picture, four diagrams, eleven chemical equations, one video and two information tables in her teaching. In her first lesson with the Grade 12 class, Mrs Meyer connected the concept of electrolytic cells of the Grade 11 work of redox reactions through brainstorming. The background knowledge solicited from learners was that of the definition of oxidising and reducing agents, reduction and oxidisation processes. A diagrammatical representation of a red cat sitting on the head of an ox was used to summarise and help learners remember, where oxidation and reduction take place, see Figure 7.12 (a).

(a) (b

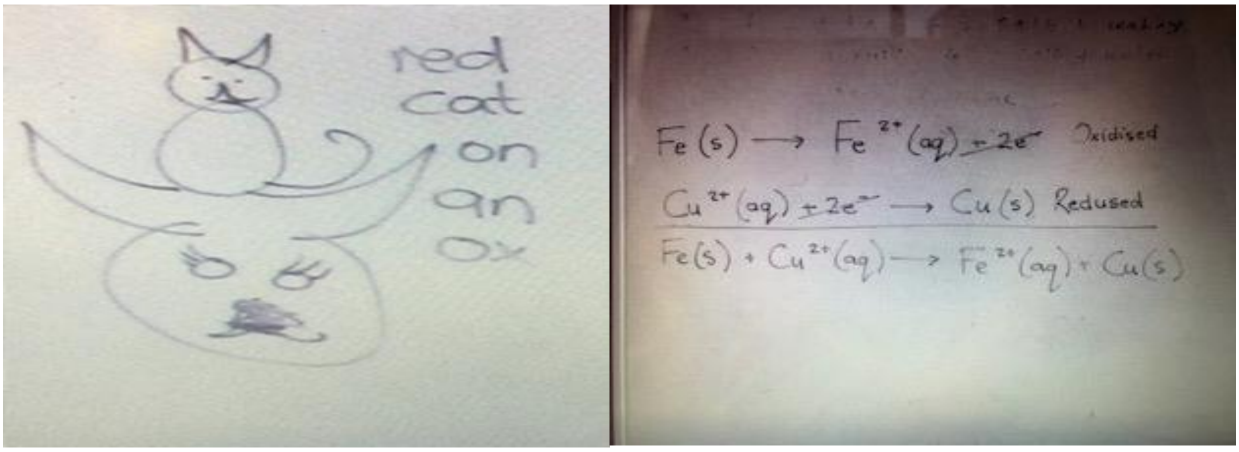


Figure 7.12: Meyer's use of a diagram and chemical equations as a mode of representation

The words ‘red cat on an ox’ represented the following phrase; reduction reaction takes place at the cathode and oxidisation reaction takes place at the anode. Like in Mrs Meyer’s Grade 11 class learners were not given an opportunity to engage with the diagram to show their understanding. As stated earlier in this chapter, a mode of representations must be used by both teachers and learners to augment a conceptual understanding of the concept under discussion.

A video showing a reaction between an iron nail and copper chloride followed the use of a diagram of a red cat on an ox to a macroscopic perspective of the redox reactions. From the experiment, the teacher wrote the chemical equations on the whiteboard (Figure 7.12 (b)). Since it was a recapping exercise one would expect learners to have an idea of how to write the half-reaction equations and the full chemical ionic equations from their Grade 11 work. But Mrs Meyer did not engage the learners for their input.

The use of the chemical equations by the teacher was followed by the use of a standard reduction potential table. The teacher showed learners how to use the standard reduction potential table to identify and interpret the reduction and oxidation half reactions. In the first lesson, the teacher managed to use four modes of representations which were a diagram, video, chemical equations, and a table. She used these multimodalities in a proper sequence and in a manner that was relevant to the understanding of the concept. Learners were not given a chance to interact with the modes of representations during the teacher’s lesson presentation. Nonetheless, learners were allowed to engage with the modes of representation during group discussions.

The learner discussion emanated from the electrolysis of aqueous potassium iodide experiment that was demonstrated by the teacher. Learners were given questions to answer in groups and were supposed to use all the information at their disposal and illustrated by the teacher during her presentation. The diagram below shows a photo screen of one of the groups’ work.

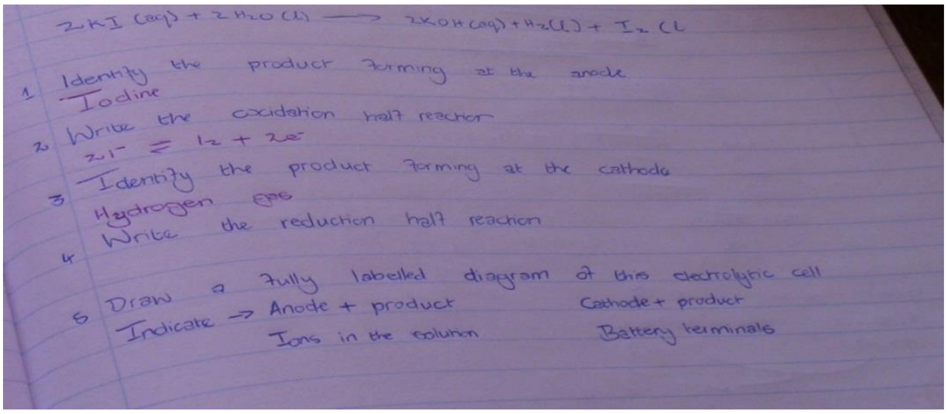


Figure 7.13: Learners' work on a class activity about electrolysis of potassium iodide solution

Unfortunately, the group discussion could not be transcribed as the teacher's voice overshadowed the learners' voices as she was explaining common misunderstandings which she identified as she moved around the groups. Nevertheless, some of their discussions could be followed even though with difficulty. From the experiment, learners deduced the substance that was discharged at the positive electrode. The half-reaction at the anode was easily extracted from the standard reduction potentials table. However, number 4 that required the reduction half-reaction at the cathode proved to be a challenge for the group. The learners could not identify the right half reaction that could be taking place at the cathode, from the table. The teacher had to assist by showing learners the correct equation as shown in Equation 7.1 below.

$$2H_2O_{(l)} + 2e^- \rightleftharpoons H_{2(g)} + 2OH^-_{(aq)} \qquad \textit{Equation 7.2}$$

The learners also managed to draw on their own the electrolytic cell of aqueous potassium iodine by correctly interpreting that it would be the same with the electrolysis of Brine (concentrated NaCl solution). Hence, they copied the picture of the membrane cell from the textbook and drew their diagram replacing NaCl with KI. In their discussions, learners were able to use verbal discourse, diagrams, pictures, chemical equations and the table of standard reduction potentials as their mode of representations. The five modes of representations were similar to what the teacher used during her lesson presentation except for that of the video. Instead of referring to the video learners referred to the demonstrated experiment of aqueous potassium iodide, which was relevant to what they were discussing.

Even though learners were not engaged during the teacher's lesson presentation, Mrs Meyer made sure that her questions on the group task directed learners to use the representations she intended them to use. Hence, she accomplished the same goals as those of Mrs Ndebele who engaged learners every during her explanations to enforce the use of here representation and immediately assess their understanding. How the mode of representations is presented to learners is not that important if learners would be able to link the verbatim explanations with the use of multimodalities meaningfully. Consequently, the number of modes of representation used in the classroom does not mean much if they are not linked to how they were used to support meaningful learning in the classroom.

Mr Masutha Grade 12

Mr Masutha managed to use a total of four modes of representation, which included a picture, six diagrams, 10 chemical equations and a table of information. In his first lesson, Mr Masutha used three modes of representation, namely, a picture, diagrams and chemical equations. The picture was on a transparent that was projected on a screen using an overhead projector. It was a text picture of electrolysis terms, which learners were supposed to define in groups. However, the teacher decided to have a class discussion since the period was shortened due to the Department of Education district officials' visit to the school. As learners discussed each term, the teacher illustrated his explanations to the learner contributions using diagrams and chemical equations. The teacher drew the diagrams before the lesson on a chalkboard, and these were the general electrolytic cell and electrolysis of copper (II) chloride.

The electrolytic cell diagram illustrated the electric circuit for the decomposition of a substance using electrodes and connecting wires. Copper (II) chloride was given as an example of an electrolyte that can be decomposed by an electric current. The teacher then illustrated decomposition of the substance using a fully labelled diagram of electrolysis of copper (II) chloride solution. From the electrolysis of copper (II) chloride diagram, terms such as oxidation, reduction, redox, reactions, electrolyte, anode and cathode reactions were discussed. Mr Masutha's approach was different from the approach of his Grade 12 counterpart, Mrs Meyer, who preferred to describe all these processes and then give learners an opportunity to discuss classwork halfway through the lesson. Mr Masutha discussed each process with the learners. Learners would first give their understanding of each term, and the teacher would link those terms to the modes of representation as he explained them further.

However, unlike in Mrs Meyer's classes, the learners of Mr Masutha rarely had the chance to link or use the diagrams as the mode of representation during the class discussions they only operated with the verbal discourse and chemical equations except in the second lesson. Although the teacher encouraged them to go and draw the diagrams at home, I had no authority or chance to check learners' books to assess how they used the modes of representations. In Mr Masutha's first lesson the teacher used four modes of representation, and the learners used three modes of representation that were the picture, verbal discourse and chemical equations.

In the second lesson, Mr Masutha used three modes of representation excluding the verbal discourse, which were six chemical equations, one diagram and a table of standard reduction potentials. The episode captured below shows the discussion on the movement of ions in the electrolytic cell of copper (II) chloride solution.

Turn	*Speaker*	*Translation*
21	*Masutha*	*We are going to do a demonstration to show electrolysis of copper (II) chloride. Who can tell where these* Cu^{2+} *ions are gonna go? To which electrode do you expect the copper (II) ions to go?*
22	*Terrence*	*From the diagram to the negative electrode, which is the cathode?*
23	*Marshal*	*No to the anode*
24	*Masutha*	*What does the anode attract?*
25	*Marshal*	*Negative*
26	*Masutha*	*So, are you saying copper (II) ions are negative*
27	*Class*	*No.*
28	*Masutha*	*So, why are you saying the anode? The diagram will guide you, so use it.*
29	*Marshal*	*Ok, negative electrode attracts positive ions.*
30	*Masutha*	*Hence, Terrence is correct it migrates to the cathode.*

The discussion on the excerpt above was after the learners had drawn the electrolytic diagram shown in Figure 7.14 (a) below. Hence, Terence could answer the teacher's question without a problem by referring to the diagram.

(a) (b)

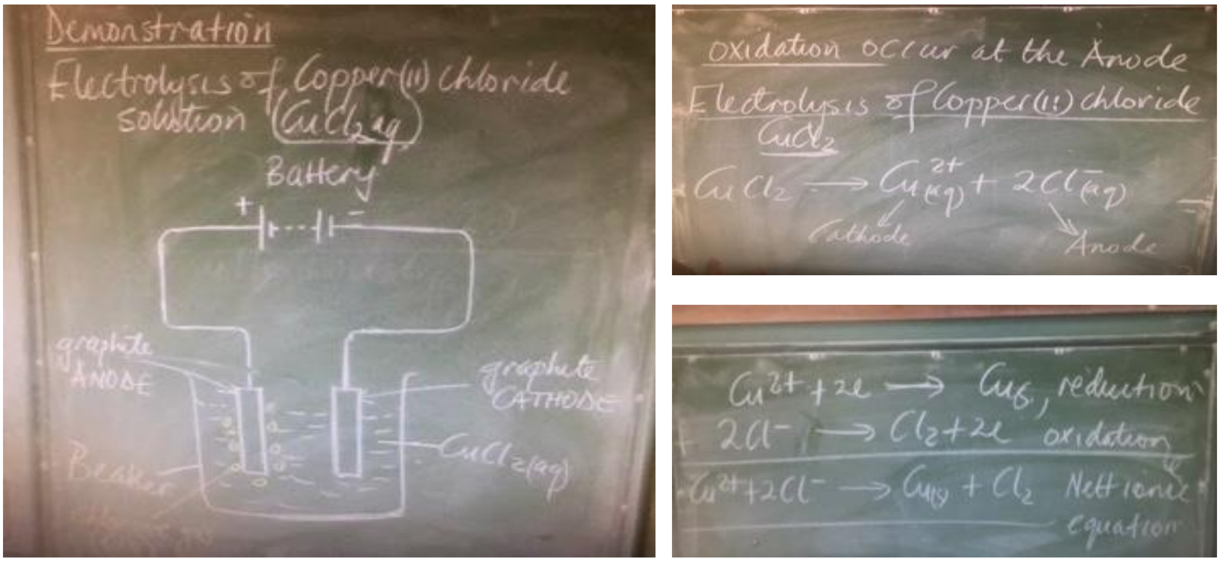


Figure 7.14: Mr Masutha's use of modes of representation in the second lesson

However, Marshal refuted Terrence’s contribution and the teacher through probing questions and referring to the diagram managed to convince Marshal that Terence was correct. Marshall was convinced about Terence’s contribution when he managed to conceptualise that the cathode, which is the negative electrode, attracts positive ions. Hence, the teacher encouraged him to use the diagram of the electrolysis of copper. As the discussion progressed, the teacher wrote the chemical equations illustrating where each ion species was migrating to (see Figure 7.14 (a)). After the demonstration, the discussion continued as learners contributed to the writing of the ionic equations as shown in Figure 7.14 (b). Mr Masutha encouraged learners to use the standard reduction potential table if they are not sure of their half-reaction equations. As the teacher engaged with diagrams, chemical equations and tables, learners were being encouraged to use more than one mode of representation to ensure conceptual understanding. The trend of using multimodal representation continued in Mr Masutha’s third lesson, and he maintained his approach to engaging learners in a whole class discussion.

Form these six case studies; it is evident that teachers who use multimodal representation increase their learners’ chances of understanding the scientific concept being discussed. Mrs Ndebele, Mrs Meyer and Mr Johannes used the greatest number of modes of representations in explaining one scientific concept. As teachers used multimodalities, their learners were able to use the same modalities in their explanation of the scientific phenomena. However, learners do not follow teachers blindly; they are active participants who can meaningfully add value to the teaching and learning process if given an opportunity.

Learners in Mrs Ndebele's Grade 11 and Mrs Meyer's Grade 11 showed that they are not blank slates; rather they use their previous knowledge, even from other learning areas, to bring solution and meaning to the problem at hand. During the group discussions, learners in these two classes, at different schools, managed to derive mathematical expressions that the science teachers had not taught them. The mathematical expressions proved to be useful to the understanding of the calculation of oxidation numbers by other learners. Therefore, it is important to afford learners an opportunity to participate in the classroom discourse and should not be treated as recipients of teacher's content knowledge narrations. Nevertheless, learners should be viewed and involved in the teaching and learning process as active participants, who bring value to conceptual knowledge building.

7.2 Approach 5: moving between different scales and levels of explanation

The previous section discussed how each teacher made links between modes of representation such as diagrams, tables, chemical equations, pictures, mathematical expressions and models in the teaching and learning of scientific concepts. Approach five involves linking different scientific explanations at different scales of magnitude in the context of teaching and learning chemistry, and these are *macroscopic*, *sub-microscopic* and *symbolic* levels (my emphasis) (Scott et al., 2011). The symbolic level is referred to in this approach, but it should not be differentiated from the modes of representations that were discussed in approach 4. Johnstone (1991) argues that symbolic level comprises maths and formulae. While Treagust (2007) identify symbolic features as pictorial representations, algebraic and computational forms and Devetak et al. (2009) further includes symbols of elements, chemical formulae and equations, mathematical equations and graphical representations to be part of the symbolic level. Hence, the symbolic level and modes of representation would be treated as the same concept. The macroscopic level is physical, represented by experimental activities, tangible, observable or visible, and sensory phenomena (G. Chittleborough & Treagust, 2007; Devetak et al., 2009; Jaber & BouJaoude, 2012). The same authors concur that the sub-microscopic level is also real, but rather encompasses invisible chemical species such as atoms, elements, molecules and electrons.

The study of chemistry, mainly abstract chemical concepts such as electrolytic cells and its underlying concepts, requires an understanding and moving between the macroscopic, sub-microscopic and the symbolic scales and levels of explanation (Johnstone, 1991; Scott et al., 2011). Scott et al. (2011) refer to the macroscopic and sub-microscopic as phenomenological and theoretical levels, respectively, and argue that when teachers move between these two scales or levels of explanation, they must be extremely explicit to prevent losing learner's concept comprehension.

Observations made at the phenomenological level are explained at the theoretical level, the sub-microscopic level and the symbolic level communicate the phenomena at an abstract level (Devetak et al., 2009). Johnstone (2000a) argues that the inability to work and think about the chemical phenomena in all three levels concurrently can be the source of several misapprehensions in chemistry. Hence, the need for the teachers to be able to move between the three levels of explanation. The teachers' ability to move between these levels of explanation should be made explicit during the teaching and learning process. Therefore, the research seeks to evaluate what scales/levels of explanation were used by the five teachers and how they were used during the teaching-learning process of electrolytic cells and its fundamental concepts.

Appendix E shows the frequencies of the three levels of explanations as used by each teacher during the three lessons. Table 7.3 exhibit the summary of each level of explanation per teacher per grade.

Table 7.3: Scales of explanations per teacher per grade

Teacher	Grade	Macro	Micro	Symbolic
Zulu	10	5	0	11
Johannes	10	21	3	27
Ndebele	11	3	3	26

Meyer	11	10	0	30
	12	8	6	19
Masutha	12	9	6	18
Grand Total		56	18	131

No trend could be deduced from the use of the three levels/scales of explanation per teacher per grade. The use of macroscopic scale depended on the school's resources and the teacher's resourcefulness. For example, Mr Johannes was not using the school's laboratory as it was used as a home classroom by another teacher. The laboratory was under-equipped, and he relied on borrowing substances from nearby former group C schools. Whereas Mrs Meyer and Mr Masutha were teaching in laboratory classrooms with moderate equipment and chemicals, but both had less experimental activities than Mr Johannes. Graphical representation was used to visualise how each teacher used these levels of representations, see Figure 7.15 below.

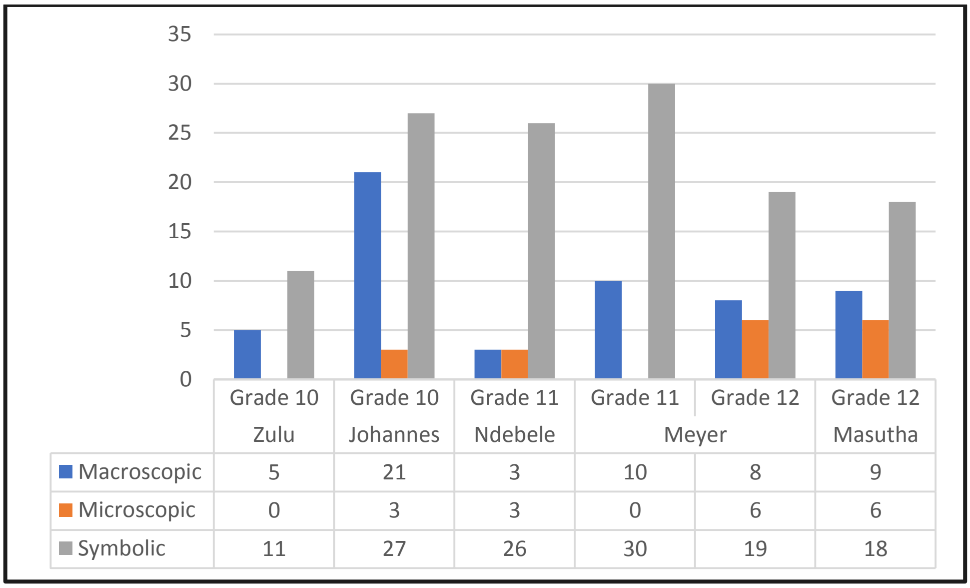


Figure 7.15: Levels of explanations per teacher per grade

Figure 7.15 above shows that the symbolic level was the most used by all teachers across the six classes under investigation. The macroscopic scale of explanation was the second highest used among the three levels/scale of explanation with Mr Johannes scoring a total score of 21. Mr Zulu and Mrs Ndebele used the macroscopic scale the least with a score of 5 and 3, respectively. Mrs Masutha and Mrs Meyer comparably used the macroscopic level with an average score of 9. Mr Zulu and Mrs Meyer did not use microscopic level in all their lessons in Grades 10 and 11, respectively. Mrs Meyer and Mr Zulu used the microscopic level in their explanations more than any other teacher in the study with a score of six each. The five teachers used a total of 56 macroscopic, 18 microscopic and 131 symbolic levels. Figure 7.16 shows a percentage pi-chat representation of the three levels of explanation.

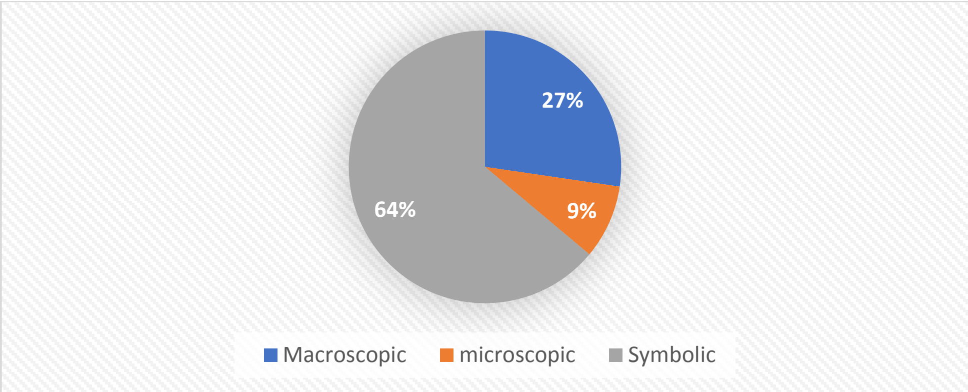


Figure 7.16: Percentage representations of different scales of explanation

The pie chart in Figure 7.16 above illustrates how each level of explanation was used by each teacher percentage wise in the 18 lessons observed across the six classes at the FET phase. Overall, symbolic was the most used level of explanation, and the microscopic was the least used level. Symbolic level made up 64%; macroscopic accounted for 27%, and microscopic scored slightly below 9% of the total explanations of all the teachers. From the pie chart graph, it is clear that, in most cases, the three levels of explanations were not used simultaneously as the percentages are not proportional. The sub-microscopic was superficially used in the teaching of electrolytic cells, redox reactions and reactions in aqueous solutions. Al-Balushi and Al-Hajri (2014) argue that shallow experience with the theoretical level leads learners to miss the opportunity to meaningfully apprehend the interrelatedness of the macroscopic, sub-microscopic and symbolic scales of elucidation. Chemical phenomena explanations depend on understanding the behaviour of sub-microscopic particles (G. Chittleborough & Treagust, 2007); hence teaching strategies should reasonably include the theoretical level of explanation. However, it was not the case in this study as symbolic was used seven times more and macroscopic was use three times more than the theoretical level. To evaluate the effectiveness of the used scales of explanations analysis of the different combinations of the three levels was done per individual teacher per class.

Mr Zulu Grade 10

As eluded above in the Grade 10 class taught by Mr Zulu, there was no reference or explanation of the behaviour of particles at the sub-microscopic level. Hence, learners were subjected to either a single level or double level of explanations using macroscopic and symbolic scales only. As shown in Table 7.3, Mr Zulu had only five episodes where he used macroscopic level of explanation that is two experiments in lesson 2 and three experiments in lesson 3 when he was doing experimental demonstrations. He did two experiments of testing sulphate and carbonate ions in lesson 2 and testing of three halide ions (chloride, Bromide, and iodide) in lesson 3. In all the demonstrations, the teacher experimented without learner involvement. There was only one incident where he asked a learner to do a demonstration for the test of sulphates by just mixing the two solutions only.

After the experiment, Mr Zulu wrote word equations and balanced symbolic chemical equations for each experiment. He narrated the reaction process without explaining that ion exchange takes place during the reaction at the particulate level. His emphasis was only on balancing of the equations than what has happened at the macroscopic level. The teacher operated at the symbolic and macroscopic level. However, the learners operated at the macroscopic level only as they were not involved in the explanation and writing of the chemical equations even to predict the products formed. When leaners are not exposed to the theoretical and symbolic levels, they remain at the macroscopic level and not able to conceptualise the scientific language of chemistry that relies on the three levels (Al-Balushi & Al-Hajri, 2014). On the part of learners, the explanations remain incomplete and being unable to understand chemistry concepts because they would not be in a position to move among the three levels.

Mr Johannes Grade 10

Grade 10 class of Mr Johannes was exposed to an array of experiment demonstrations; a visible or sensory phenomenon followed every concept that was discussed. The teacher ensured that every experiment was followed by the symbolic scale, and the particulate level was used on three occasions in discussion with the learners. The nature of macroscopic and sub-microscopic levels that were discussed in lesson one are shown in Table 7.4 below.

Table 7.4: Macroscopic and sub-microscopic scales of explanation by Mr Johannes in lesson one

Lesson	Macroscopic	Sub-microscopic
1	Dissolving of $NaCl_3$ solid in water	Diagrams showing sub-microscopic representations of solid sodium chloride and sodium and chloride ions solution
	Dilution of $AgNO_3$ solution with water	Diagrams showing particles of solid silver nitrate, silver ions and nitrate ion solution
	The reaction of silver chloride and sodium nitrate	Diagrams showing sub-microscopic of silver chloride lattice

Table 7.4 above illustrates how the macroscopic and sub-microscopic levels were distributed for Mr Johannes's first lesson. The sub-microscopic level of explanation was only discussed with learners in lesson one only, and that is when learners were exposed to all three scales of explanations. In the second and third lessons, the teacher referred to the first lesson about the theoretical level of explanation. That is in the two last lessons both teacher and learners were operating on two levels which were macroscopic and symbolic. The teacher began the lesson by recapping the previous lesson, which was about the dissolution of salts in water. After the recap discussions, the teacher gave learners worksheets with sub-microscopic representations, see Figure 7.17 on the next page. Below is an extract showing how Mr Johannes introduced the concept of explaining the chemical phenomenon of dissolution and precipitation reaction.

Turn	*Speaker*	*Transcript*
15	*Johannes*	*…… So today we are going to be using solutions that are going to have those ions, are we together. What I am going to do right now I shall first give you worksheets, and then I am going to demonstrate an experiment in which we are going to have ions reacting in a precipitate reaction in solution.*

The teacher performed the three experiments, as shown in Table 7.4 above. Before doing the experiment, learners were asked to predict by drawing what would happen when the two solutions were mixed.

The teacher wanted learners to draw the diagrammatical representation at the macroscopic level, what the learners had seen during the experiment. After that, the teacher asked learners to discuss in groups of five and answer questions on a worksheet that the learners were given before the experiment began. The worksheet had questioned that asked learners to choose a letter that corresponded to the demands of the question. For example, the second question said that "I think that the particles in silver nitrate solution are best represented by diagram…". Learners were supposed to choose a letter corresponding to the diagram that represented what they thought was correct and they were to explain their choice, as shown in Figure 7.17 below.

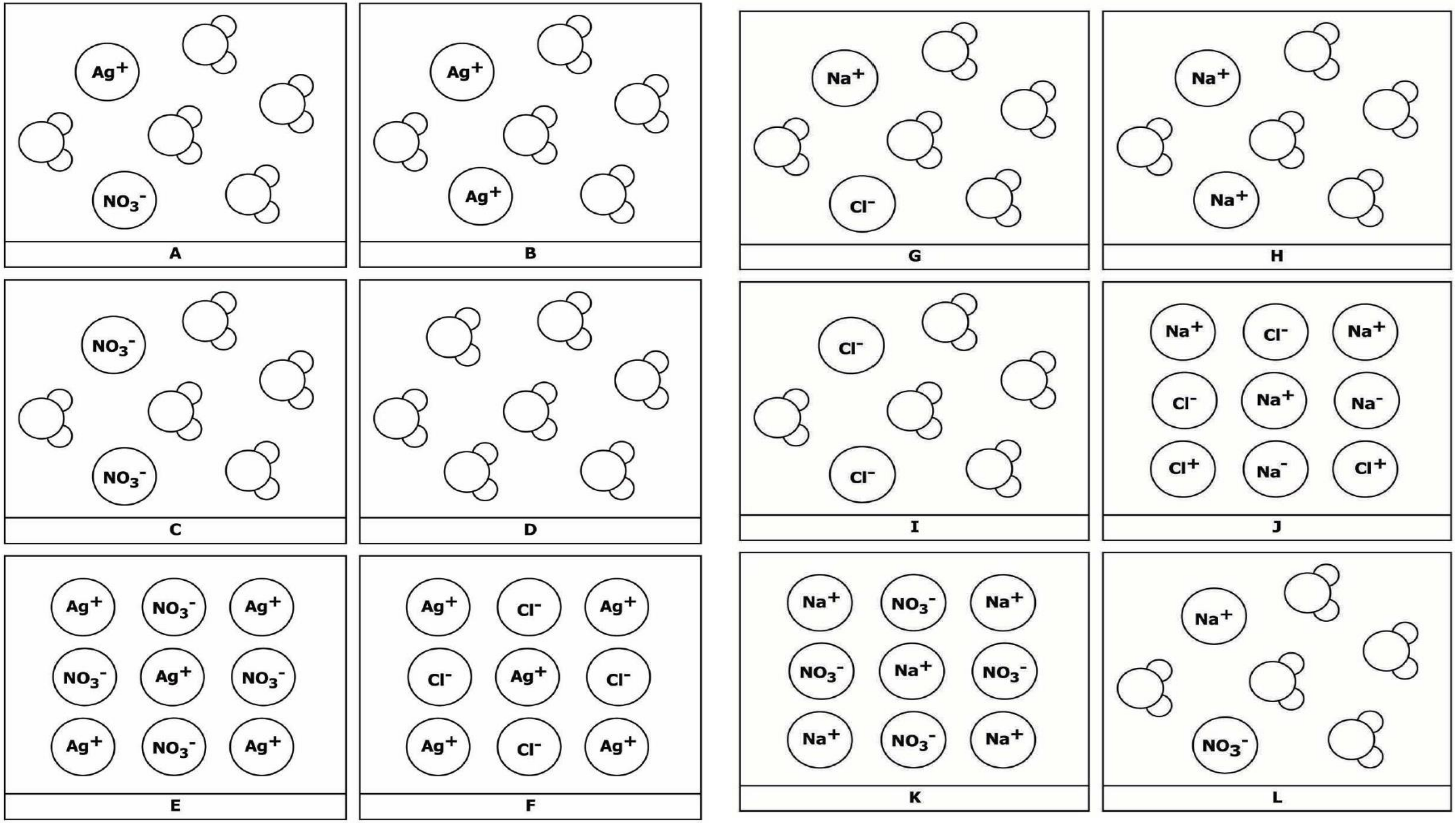


Figure 7.17: Sub-macroscopic representation diagrams for precipitation reaction of silver chloride

Learners in the social setting of a group discussed the activity, and most of the groups were able to identify the diagrams. Unfortunately, their discussions could not be captured but as the teacher was moving around monitoring learner progress his interactions with various groups were captured as shown in the excerpt below.

Turn	*Speaker*	*Transcription*
134	*Johannes*	*Now we would want to identify the ions that we had in sodium chloride solution and silver nitrate solution before I added them together into this beaker. We must also identify the ions we now have after mixing the two reactants. So, we are going to use the worksheet that I gave you.* *In your group, you are going to discuss and identify the particles that are in sodium chloride. You will refer to this table are we together?*
135	*Class*	*Yes*
136	*Johannes*	(the teacher moves around the groups as learners discuss several learners were having difficulty understanding the activity until the teacher had to address the whole class explain using chemical equations on the board). *Pupils listen as guidance; when you add sodium chloride into the water, it dissociates into a sodium ion and chloride ions. Now, this means sodium ion is surrounded by water molecules; chloride ions are surrounded by water molecules. So, when you are answering the first question you look for a diagram that is having sodium ions surrounded by water molecules and chlorides ions, you do the same for silver chloride.*
137	*Class*	*Ooh ok!*
138	*Johannes*	(Teacher on the 3rd group): *that is correct move on.* (Teacher on the 4th group)*: that is correct move on.* (Teacher on the 5th group)*: how far here, remember water has three atoms are we together remember H_2O and give a reason.*
140	*Group 5*	*Yes, now we get it*
141	*Johannes*	*On the 6th group* *Which one is the solution? Do you see water here please think again you must have silver ions and nitrate ions surrounded by water? Lucky's drawing is correct, but there is a diagram on the worksheet that represents this, please look for it.*

The teacher did not give up on learners when they were having problems with the activity. Instead, he further explained and gave them clues (turn 136) for the success of the activity. As the teacher moved around, several groups were correctly matching the questions with the diagrams and giving correct explanations as affirmed by Mr Johannes (turn 138). In turn 141, there is an interesting comment made by the teacher when he was helping group six learners, he disputed the choice the group had made, he went on to give them a clue to identify the correct diagram successfully. However, Mr Johannes identified a correct diagram that depicted the correct representation of the dissolution of silver nitrate drawn by one of the group members, Lucky. Instead of just matching the letters with the given diagrams, the learner drew his diagram. Which the teacher confirmed that it was correct and was the same with what was on the worksheet and learners had to identify it.

Lucky just showed how understanding learners could be when they are taken through teaching strategies that foster conceptual understanding. Considering Table 7.4 that has all the experiment the teacher did with learners in lesson one. Mr Johannes did not do the experiment on the dissolution of silver nitrate, but he brought a solution of already made and he diluted it. That means luck had to apply his understanding of the sodium chloride dissolution process to that of silver nitrate. Unfortunately, this project did not seek to research on what learners wrote in their workbooks as such. It was going to be of interest to see how Lucky represented the sub-microscopic particles of silver nitrate in water. Nonetheless, teacher's comments are sufficient enough to convince us that the learner inevitably drew relevant theoretical representations of silver nitrate in water. Hence, in this first lesson both the teacher and learners managed to operate simultaneously on all three scales of explanations as exhibited in Figure 7.18 below. The diagram was adopted and modified from Johnstone (1991) diagram of the triangle of levels of thought.

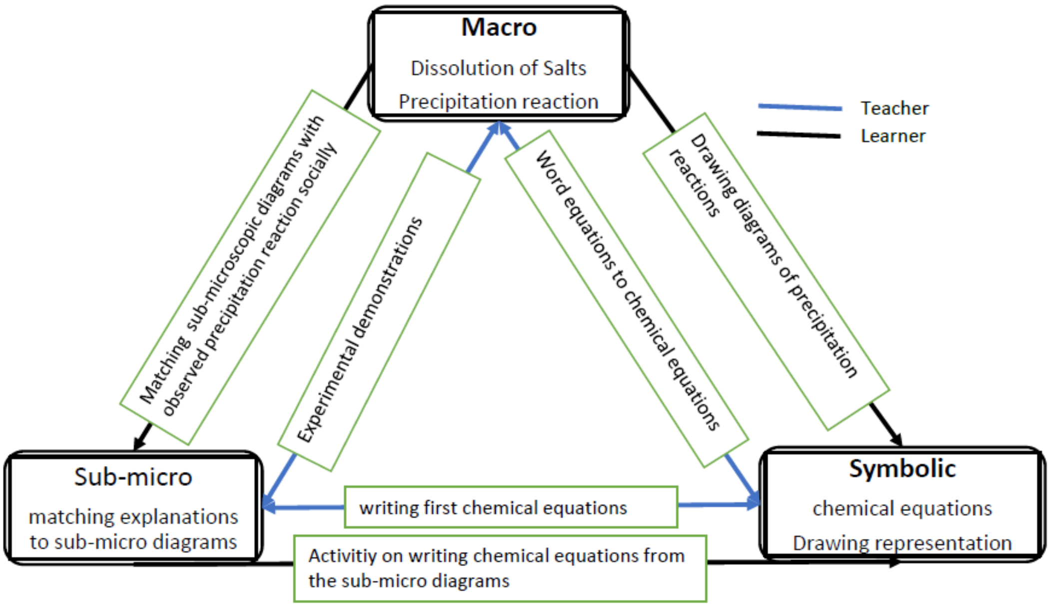


Figure 7.18: The triangle of levels of thought for both teachers and learners

The macro and sub-micro represent the macroscopic and sub-microscopic levels. The events of the first lesson are shown in Figure 7.18, regarding how the teacher managed to move himself and his learners from one level of explanation to the other. The inside triangle represents the teacher's movements, and the outside triangle represents learners' movements from one level to the other according to recorded classroom proceedings. The double arrows on the teacher's triangle show that Mr Johannes could explain the concepts of precipitation and dissolution using all three levels of explanations. He moved back and forth whenever it was necessary, especially on turn 136 on the excerpt above. The teacher had not introduced the writing of equations; he wanted learners to conceptualise the sub-microscopic level first. However, as learners were faced with a problem of identifying water molecules, he exemplified his explanation at the symbolic scale and learners were satisfied. So, Mr Johannes after experimenting (Macro) he represented the chemical reaction by writing chemical equations (symbolic) on the board. From the use of tangible objects, he drew a depiction of how ions can be represented (sub-microscopic), and from the technical diagrams, he wrote chemical equations. Mr Johannes followed a well-organised presentation although learners did not move to and from all three levels, they were able to work with all three levels one at a time.

The outside triangle displays how the teacher moved learners from one level of explanation to the other, for the learners to meaningfully conceptualise the precipitation and dissolution concepts. Learners observed the teacher doing experiments and were made to draw what they saw (macro). Learners were being moved from the macroscopic level to symbolic level (diagrams). The activity of matching diagrams to written explanations and learners quantifying their choices with reasons, helped them to move from macroscopic level to sub-microscopic levels of explanation. Furthermore, learners were asked to write full ionic equations and net ionic equations (symbolic) using the diagrams they had chosen earlier on. The last activity helped learners to transcend from microscopic to symbolic scales of explanations.

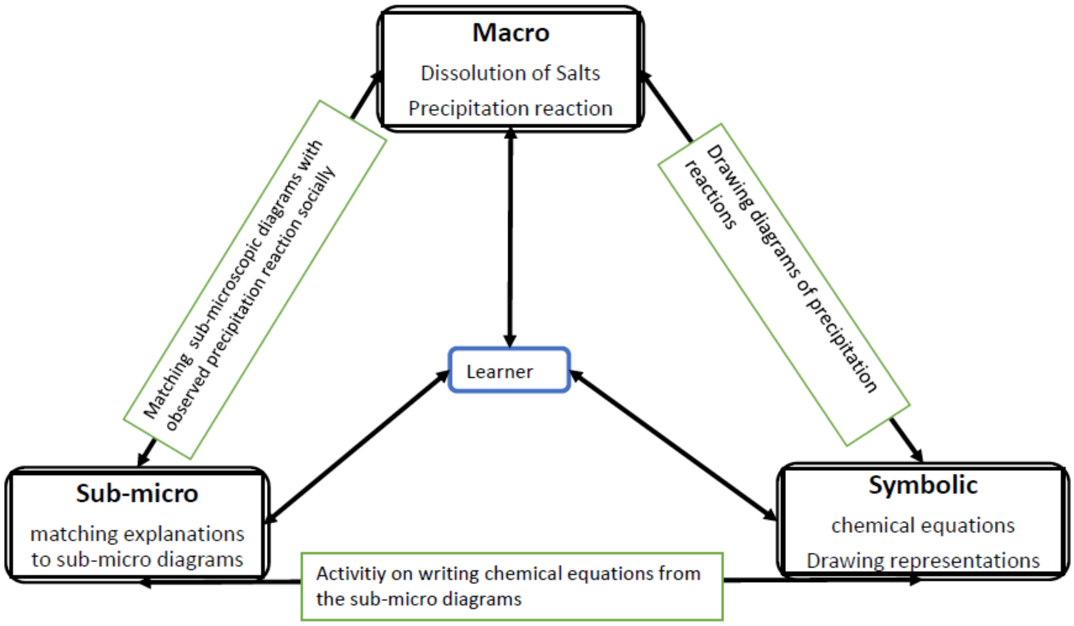


Figure 7.19: Learners' triangle of levels of thought

Figure 7.19 explains the final imaginary picture in learner's schema when a teaching strategy is inclusive of all three levels/scales of explanation. Although the learners did not move back and forth among the scales of explanations like their teacher (Figure 7.20), the three scales would exist in their cognitive schema.

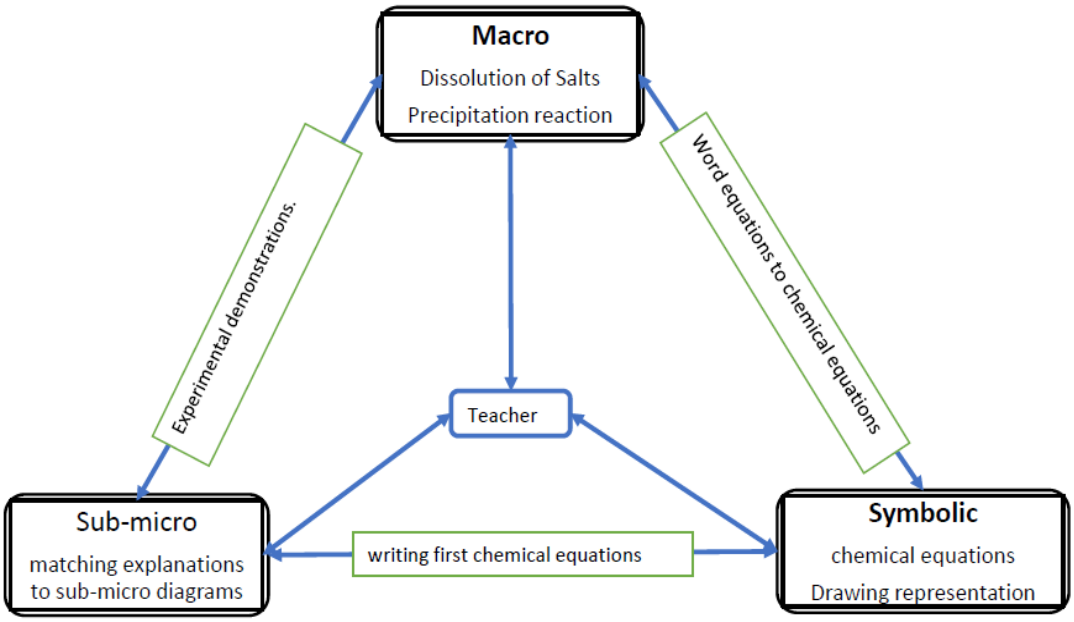


Figure 7.20: Learners' schematic triangle of levels of thought

Therefore, it is of importance for learners to be exposed to the triangle of levels of thought as suggested by Johnstone. When learners participate in all three levels in a social milieu conceptual understanding would be ensured. Smith and Villarreal (2015) argue that learners create knowledge through social mediation processes, where individuals interact with the teacher and peers.

Mrs Ndebele Grade 11

Mrs Ndebele taught redox reactions to a Grade 11 class, and she managed to use three macroscopic, three sub-microscopic, and 27 symbolic levels of explanations during her teaching. The macroscopic and sub-microscopic levels were covered in the last lesson where two experimental demonstrations were done, and one video clip was shown to the learners. In the first and second lessons, the teacher was operating on a single scale of explanation, the symbolic level.

At the beginning of the third lesson, Mrs Ndebele did corrections of the homework given to learners on oxidation and reduction reactions. Further questions and class work was done on how to identify and write equations of oxidation and reduction half-reactions in a redox reaction. Different examples were discussed in groups by learners, who then did presentations on the smartboard. Figure 7.18 in section 7.3 shows the symbolic level of explanation on redox reactions presented by learners.

Halfway through the lesson, Mrs Ndebele showed learners substances and metals she had brought in class, which were copper (II) sulphate solution, iron (II) sulphate solution, a nail, and a copper strip. She cleaned the nail with sandpaper and dipped it in a test tube with copper (II) sulphate solution and the copper strip was dipped in a test tube with iron (II) sulphate. For each experiment, there was a control that had the solution without anything in it. The experimental and control solutions were of the same concentration. The experiment set up was left for seven minutes, while the class continued with problem-solving and identification of oxidation and reduction half-reactions.

After seven minutes the teacher draw out the nail from the test-tube with copper (II) sulphate solution and the part of the nail that was dipped into the solution had turned brown. The teacher circulated the nail hang on a string of thread to every individual learner in the classroom. She asked learners' opinions on what had happened to the nail. Most of the learners were whispering that the nail had rusted. The teacher then probed learner thinking by referring to the colour difference of the solutions between the copper (II) solution that had an iron nail and the control that did not have the iron nail. Learners correctly observed that the experimental set up had a lighter blue colour than the control. Learners could not explain the cause of colour change, and the teacher further asked about the iron nail, see the extract below to the discussion that followed.

Turn	*Speaker*	*Transcription*
107	*Clement*	*I think the iron nail has corroded …*
108	*Celo*	*It has changed the colour*
109	*Ndebele*	*Yes, it has changed colour, first Clement said it has corroded, and the second point what did you say? Ok yes, Tibo!*
110	*Tibo*	*The nail is corroded meaning that it has gained oxygen for it to corrode. …*
111	*Ndebele*	*Really, is the nail corroded? Do you remember the reaction of vinegar with steel wool when we were doing acids and bases? Do you think what happened then is the same reaction here? Ok, let us watch and listen to the video clip here and see what has transpired.*

After the conversation above, it became clear why learners thought the nail had corroded. The notion emanated from learners' experience of rusting of steel wool as referred to by the teacher (turn 111). Tibo correctly explained the oxidation of iron nail regarding its reaction with water and not according to electron transfer and its reaction with copper (II) ions. Mrs Ndebele was supposed to explain the difference between the two reactions. However, she opted for the video clip to clarify the matter. The diagrams in Figure 7.21 shows Mrs Ndebele's experimental setup, the video's experimental and the explanation that was played from the video.

(a) (b) (c)

Figure 7.21: Macroscopic and sub-microscopic levels in Mrs Ndebele's class

Figure 7.21 (a) shows the two experiments set by Mrs Ndebele as discussed above. Unfortunately, the class could not discuss the experiment on copper strips in iron (II) sulphate because of time. Figure 7.21 (b) demonstrates an experiment that was played on the video clip, and that was a repetition of what Mrs Ndebele had demonstrated to her learners. Figure 7.21 (c) displays the sub-microscopic level of explanation of the reaction between iron and copper (II) sulphate. In the video, iron atoms were seen leaving the nail as ions (Fe^{2+}) going into the solution to form Iron (II) sulphate ($FeSO_4$). Copper (II) ions (Cu^{2+}) were seen changing into a copper atom as there were deposited on the surface of the iron nail as a brown substance. The narrator on the video explained that iron is more reactive than copper and was oxidised by losing electrons and those electrons were accepted by copper (II) ions causing it to be reduced to copper atoms. The brown copper atoms were deposited around the iron nail.

After the video clip learners were convinced by the teacher’s explanation that the iron nail did not rust but was oxidised. Indeed, the iron nail was oxidised but through the loss of electrons and the resulting species going into solution. Learners also appreciated that the brown colour was not the colour of Iron (II) oxide but that of copper atoms that were reduced and precipitated from solution onto the iron nail surface where the electron exchange took place. The teacher rounded up the discussion by giving learners homework of writing the oxidation and reduction half-reactions of the experiment between iron and copper (II) sulphate and the full ionic equation thereof. Learners were further asked to identify the oxidising agent and the reducing agent.

Mrs Ndebele's approach was different from that of Mr Johannes. In the first two lessons, Mrs Ndebele mainly operated on the symbolic level where learners discussed and solved problems using the symbolic level of explanations. She then introduced a macroscopic level of explanation in the third and last lesson which was immediately followed by the microscopic scale of explanation. Learners were then asked to symbolise the invisible as visualised on the video through writing chemical equations.

At the end of Mrs Ndebele's series of lessons, her learners operated on the three levels of explanations although the dominant scale was symbolic. However, as shown in Figure 7.22 below, there was no evidence from the lesson that the learners were encouraged to move from the macroscopic to the symbolic.

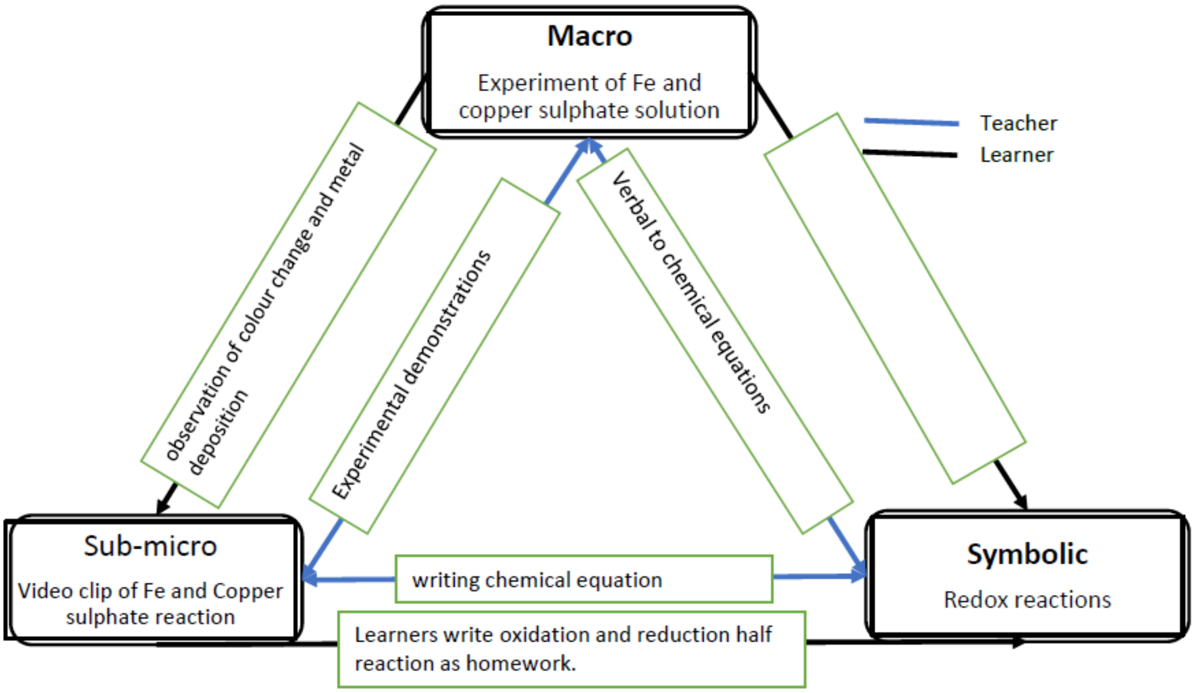


Figure 7.22: The levels of triangle of thought in Mrs Ndebele's class

During the discussion on the experiment of iron and copper sulphate solution, learners failed to explain what they observed regarding the symbolic level. They could only relate the events of the macroscopic level through the explanations from the sub-microscopic level. Hence the blank box between the macroscopic level and the symbolic level on the outside triangle that represents the learner. However, the teacher could operate on all scales of representations, but her approach and sequencing of lesson events were not adequate to allow learners to move back and forth between the levels explanation. Therefore, Mrs Ndebele's learners operated effectively between sub-microscopic & symbolic, and macroscopic & sub-microscopic. Nonetheless, no evidence could be found in the lessons that learners operated between macroscopic and symbolic levels.

Mrs Meyer Grade 11 & 12

Mrs Meyer's approach was almost the same in both Grade 11 and 12 classes, hence making links between levels/scales of explanation were simultaneously analysed. In the Grade 11 lesson, Mrs Meyer did not refer to the sub-microscopic level of explanation; she only operated on macroscopic and symbolic levels. Moreover, the symbolic level was used three times more than the macroscopic level. Thus her approach was pre-dominantly symbolic, like that of Mr Zulu and Mrs Ndebele. Although Mrs Ndebele predominantly used the symbolic level of explanation, she was different from Mrs Meyer and Mr Zulu in that she used all three scales of explanation. However, Mr Zulu had a frequency score of 11 symbolic levels of explanation compared to Mrs Meyer's 30 frequency score. Therefore, Mr Zulu was only the teacher who had the least frequency score of using any of the scales of explanation during his teaching.

In her Grade 11 class, Mrs Meyer significantly used the macroscopic scale in the second lesson, where she demonstrated electrolysis of copper (II) chloride solution when explaining redox reactions. The teacher did the demonstration while learners were observers. She started the experiment by explaining the set of the electrolytic cell circuit, the carbon electrodes used and the coloured electrolyte of copper (II) chloride solution. Despite that learners had done conductivity of liquids in Grade 10. The teacher did not involve learners in her narration of the electrolytic cell set up. However, learners were involved in stating the observations that were happening at each electrode during electrolysis. A substantial brown deposit was seen at the cathode and bubbles of gas were observed at the anode. The teacher positively identified the gas as chlorine due to its smell that was like that of swimming pool water. The cathode electrode and the beaker containing the electrolyte were circulated among learners for them to carefully observe the brown deposit and the smell of chlorine that had dissolved in water respectively.

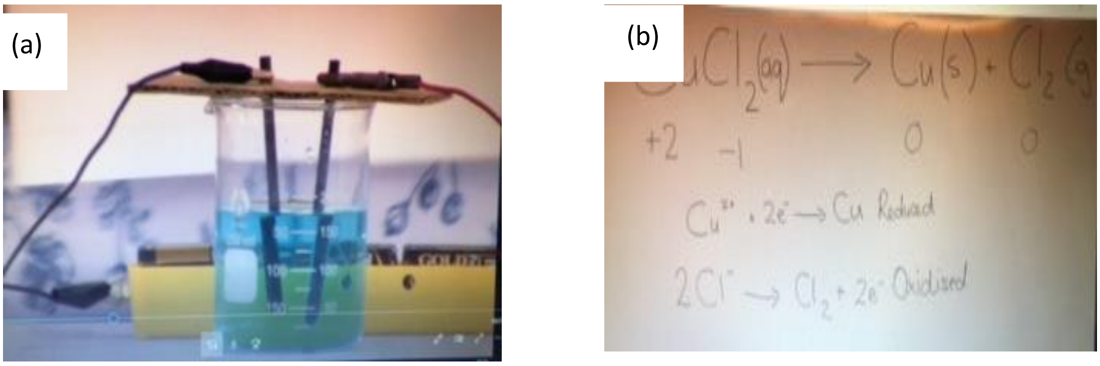


Figure 7.23: Macroscopic and symbolic representations in Mrs Meyer's Grade 11 class

The diagrams in Figure 7.23 above show the macroscopic (a) and sub-microscopic (b) representation, respectively. After the demonstration, the teacher went on to explain and write on the whiteboard the two half-reactions that took place at the anode and cathode. The reader is reminded of Mrs Meyer's style of teaching that she explained everything first to the learners with minimum learner interaction. Learners were then given a chance to discuss the concept narrated by the teacher in groups later in the lesson. Hence, she wrote the equations by herself without learner interaction. Therefore she was the only person link-making the two scales of explanations (macroscopic and Symbolic), and learners were observers, see Figure 7.24 below.

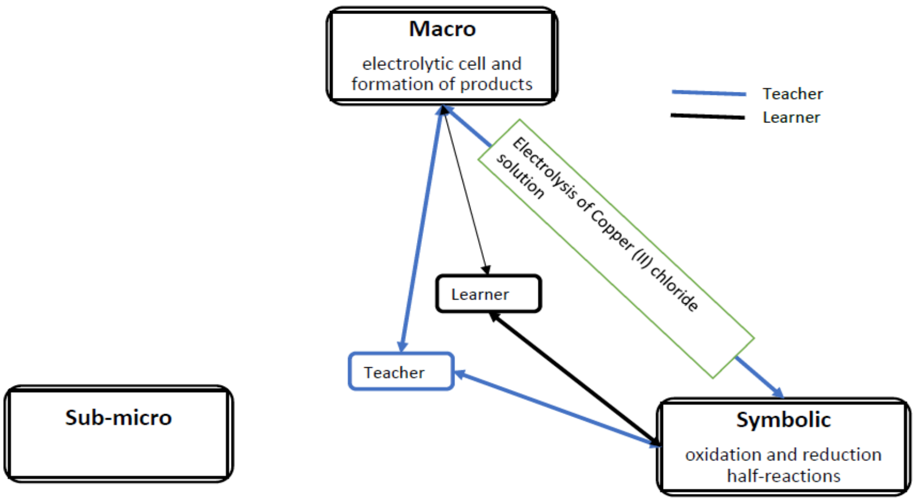


Figure 7.24: Teacher-learner cognitive representation in Mrs Meyer's Grade 11 class

The diagram above is a representation of the way the three levels of thought were enacted in Mrs Meyer's Grade 11 classes. The teacher operated between the macroscopic and symbolic levels of explanation. In the data collected there was no evidence that learners operated between the two scales of explanation, but only operated on the symbolic level. The observation they made during the demonstration of electrolysis of copper (II) chloride solution was in isolation with the questions they were given during the group discussions. Hence, there is no black arrow directly linking macroscopic and symbolic scales. However, one must appreciate that the observed tangible world of chemistry does exist in the learners' schema though unlinked to the exact symbolic scale.

In Grade 12 Meyer's first lesson was conducted verbatim with occasional reference to redox reactions (symbolic level). However, in the second lesson, she operated on three levels of explanation. When she played two videos, the first showed electron exchange at the zinc metal – copper (II) sulphate solution interface. The second video showed the experimental demonstrations of the polished iron nail in copper (II) chloride solution.

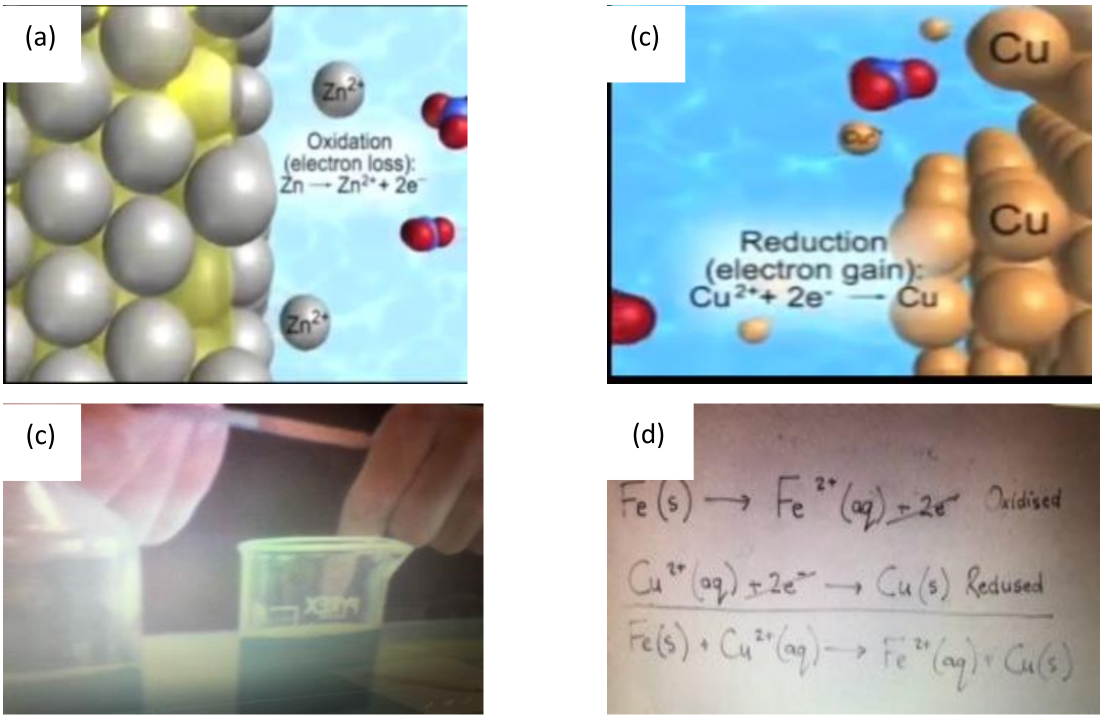


Figure 7.25: The three levels of explanation as depicted in Mrs Meyer's Grade 12 class

Figure 7.25 demonstrates four diagrams which were taken in the second lesson of Mrs Meyer's Grade 12 class. Diagrams (a) and (b) shows what happens at the interface of the solid and the solution when the zinc strip is dipped into the copper (II) sulphate solution. There simultaneous reactions of oxidation of zinc and reduction of copper. The video narration explained the reduction and oxidation processes shown by the symbolic levels of explanation in the form of chemical equations. Diagram (c) shows a second video where a polished ion nail was dipped for a minute in a beaker with copper (II) chloride when it was taken out it was covered with a brown substance. Half-reactions and full ionic equations preceded video clip explanations. As per Mrs Meyer's approach, learners were not engaged in the explanations and were not asked to write equations as per my observations.

After watching the two videos learners were asked questions that summarised what the teacher had been explaining. The questions ranged from the definition of terms such as reduction and oxidations to identifying redox half-reactions. Learners were left to apply what they heard from the teacher during her explanations. The diagrammatical representation below shows how the teacher and the learners transcended from one level to the other.

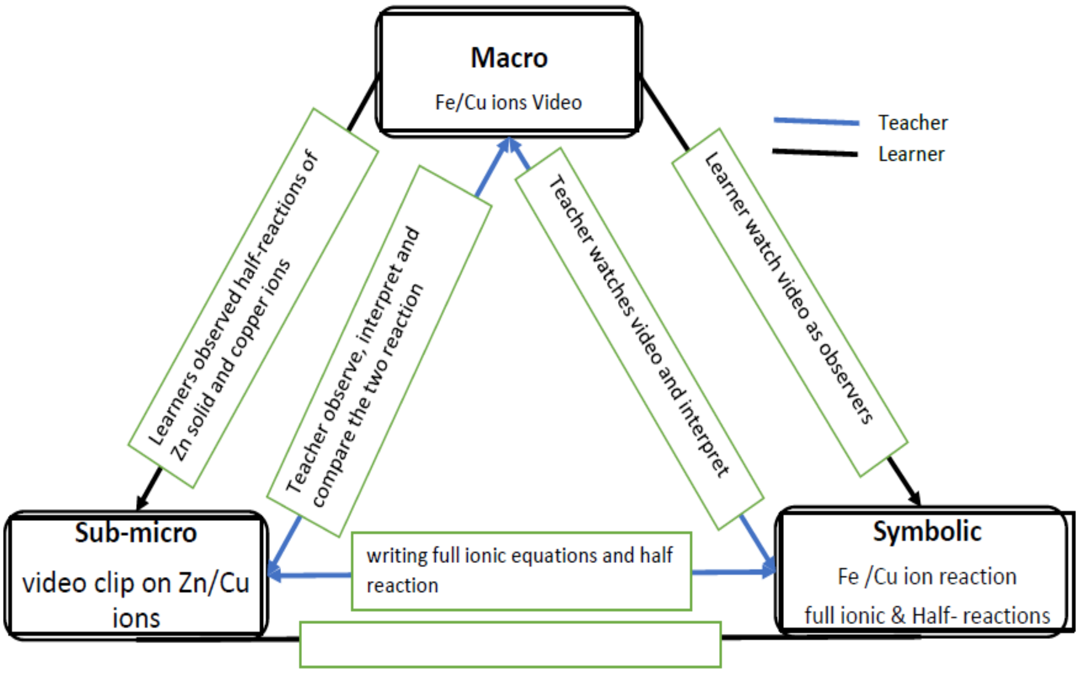


Figure 7.26: Teacher-Learner scales of explanations in Mrs Meyer's Grade 12 class

The triangle of levels of thought for both Mrs Meyer and the learners have been demonstrated in Figure 7.26 above, where the teacher was able to move back and forth between levels of explanation. Between macroscopic and sub-microscopic the teacher was observing together with learners and later in the lesson she made a comparison between the sub-microscopic and the macroscopic videos. The teacher successfully linked the macroscopic observation made on the change of colour to the chemical equation (symbolic level) of the reaction between a polished iron nail and copper (II) solution. Mrs Meyer in her explanations referred to the behaviour of microscopic particles of iron-copper (II) chloride to that of zinc-copper (II) sulphate solutions. Hence the teacher successfully transcended from one level to the other. However, it was not the same story with the learners. Observing the two videos enabled learner to make links between macroscopic – symbolic and macroscopic – sub-microscopic. Unlike the teachers' bidirectional linkages, learners' linking making was unidirectional as shown in Figure 7.26 above. Furthermore, there was no concrete evidence that learners linked the sub-microscopic and symbolic level because during the lesson no learners could be heard explaining the behaviour of particles at the molecular level. Therefore, it cannot be assumed that learners understood or did not understand as it could not be proved from the data collected.

Since it could not be verified that the learners comprehended the linking of sub-microscopic and symbolic scales of explanation, then the existence of the relationship between the two scales in the mind of the learner remained uncertain. The existence of that relationship in the learners' cognitive structures could not be guaranteed. Hence the faint line between symbolic and sub-microscopic levels as well as between the learner's mind and the sub-microscopic level (see Figure 7.28 below). However, during group discussions, learners were able to move between the macroscopic scale and symbolic level as they referred to the observation made on the iron nail – copper solution reactions. Hence, the certainty of the existence of the relationship between macroscopic and symbolic scales of representation as shown by the bold turns in Figure 7.27. Since the teacher could move between each pair of scales of explanations, then the three levels of thought are in co-existence in the teacher's schema.

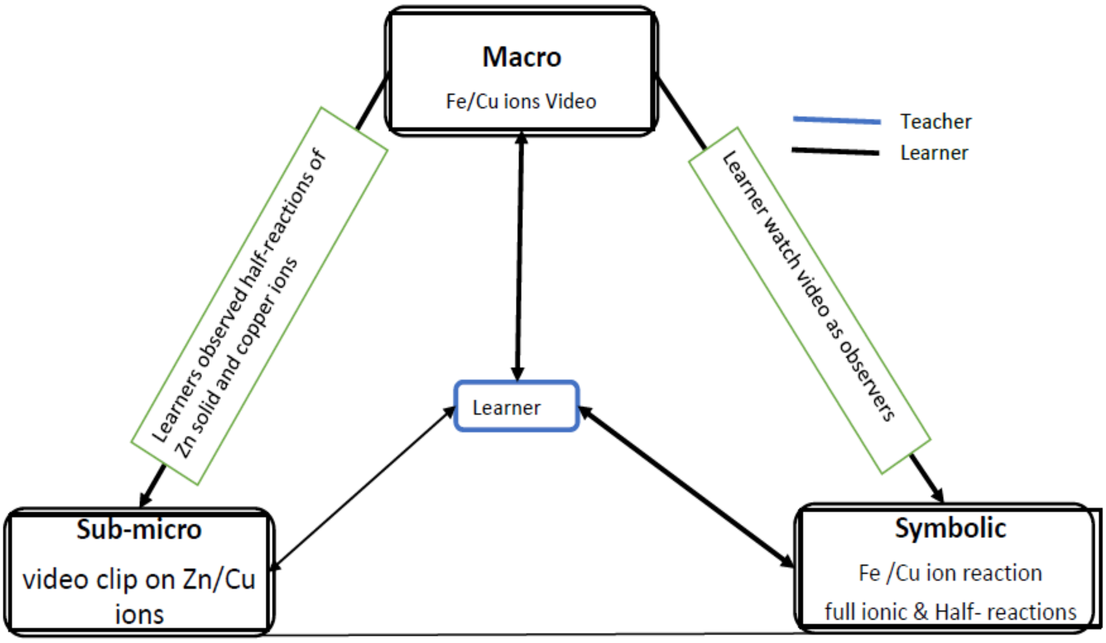


Figure 7.27: The triangle of levels of thought as depicted in Mrs Meyer's Grade 12 class

Learners only operated at the symbolic and macroscopic level in Mrs Meyer's classes. They never got an opportunity to comment or interpret the behaviour of the invisible particles, which is an integral component for conceptualising chemical phenomena as argued by Al-Balushi and Al-Hajri (2014). Leaving out the sub-microscopic level in the explanation of such abstract chemical phenomena as redox reaction compounds the difficultness of the subject as learners will not be able to explain the events taking place at a molecular level. The Department of Basic Education through the Physical Science CAPS document advice teachers to make use of these three levels of explanation when it says that;

> *Link redox reactions to oxidation numbers. In this section, care must be taken to emphasise the relationship between the symbolic (chemical reaction equations) and the macroscopic (what you see with your eyes) and sub-microscopic (on molecular level) representations (Department of Education, 2011).*

Therefore, there is a need to develop teachers on how they should incorporate the molecular level aspect of explaining scientific concepts. During the interview, Mrs Meyer and Mr Zulu confessed that it is quite difficult to find relevant material that would not bring misconceptions when showing learners the behaviour of particles at the sub-microscopic level. These sentiments were uttered by the two teachers when they were responding to the probing question: What resources do you use to illustrate the behaviour of sub-microscopic particles in your teaching?

Meyer	*Most of the resources I download them from the internet. To download the most appropriate animation or video, I must watch everything and select the one that has the minimum or no misconception. That takes time, and it is difficult to get one with no misconceptions. Unlike us, paperless schools get these videos already loaded in their smart boards.*

Mr Zulu had this to say:

Meyer	*It was easy to show learners how the particles behaved at the macroscopic level when we had the smart boards. But since the thieves stole all the smart boards in the school, it is difficult to get those materials on my own. You will need data to download them from the internet, which is very expensive. So currently will just explain verbally.*

Furthermore, teachers bemoaned lack of resources, especially relevant videos like what the government has supplied to the paperless schools in township suburbs. Hence, there is need to support teachers' through in-service training of how to use the sub-microscopic representations to explain the behaviour of particles at the molecular level.

Mr Masutha Grade 12

School E is a former group C school like school D and the schools have similar physical building infrastructure. Mr Masutha taught four Grade 12 Physical Science classes, and the class involved in the research did not clash with other classes from the other four schools involved in the research. However, Mr Masutha does not have the laptop, and data projector like his counterpart in school D. Nonetheless Mr Masutha's use of the three levels of explanation was comparable with Mrs Meyer's in school D. They each managed a frequency of six sub-microscopic levels of explanation. Mr Masutha managed nine macroscopic and 18 symbolic while Mrs

Meyer managed eight macroscopic and 19 symbolic levels of explanation in the three lessons observed. Contrary to Mrs Meyer's approach to teaching, Mr Masutha preferred a class discussion throughout the lesson, where he will oversee the pace and content of the discussion. He believed that at Grade 12 there is no time to waste, so he did not use group work because learners take time to reach a consensus and he did have that time.

Mr Masutha used the chalkboard extensively, and his illustrations of symbolic and microscopic were all presented on the chalkboard. The school had a data projector which was used by the head of the science department and could rarely be shared. So, he only drew diagrams once on the flipping chalkboards for the entire topic and used them with all the classes he taught in the same grade. Hence, on the chalkboard there were different electrolytic cell diagrams for processes of extraction, refining and purification see Figure 7-28 below.

Figure 7.28: Diagrams representing different electrolytic cells

Coloured chalks were used to differentiate illustrations from explanations, and all explanations were erased before the next class began. The diagram above was photo screened before the observation of the third lesson where most of the sub-microscopic levels of explanations were captured. The diagram on the left in Figure 7.29 shows a blister copper refining electrolytic cell; the centre diagram exhibit extraction of aluminium metal; and the diagram on the right depicted the industrial process of electrolysis of Brine. The teacher erased most of the explanation which he would have done with one class. As he was discussing each concept the diagrams would be fully labelled using words and sub-microscopic representations, see Figure 7.29 below.

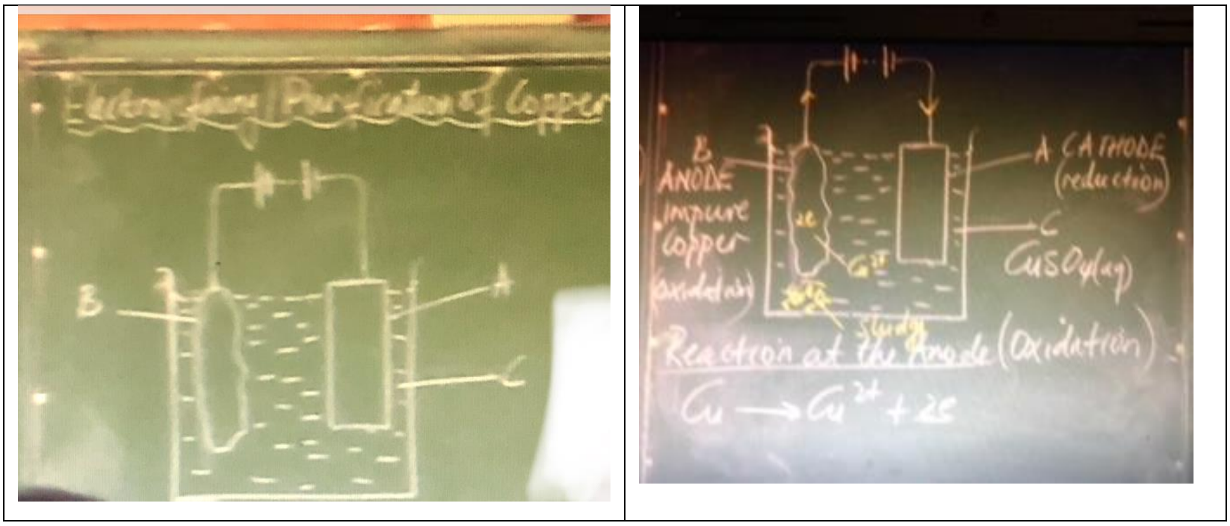


Figure 7.29: Diagram representation of electrolytic refining of blister copper

The two screenshots in Figure 7.29 shows the discussion around the concept of purification of copper. As the lesson progressed, the teacher would probe learner ideas about the concept directed to what they would have seen during the experiment. Learners were answering questions about the labelling of the diagram, while the teacher was writing on the board. Figure 7.29 (a) displays unlabelled electrolytic cell of electro-refining of blister copper (electrode B). By the end of the discussion of the concepts Figure 7.29 (a) was transformed to Figure 7.29 (b) and the labelling depicted all discussions around the concepts. The discussions were around firstly, the macroscopic level as observed from the experiment — secondly, the symbolic levels as exemplified by the chemical equations and the diagram. Thirdly, the sub-microscopic level as illustrated by the articles written in yellow coloured chalk.

Although Mr Masutha did not have group discussions, his learners were fully engaged in all the levels of explanation, that is symbolic, molecular level and in doing experimental demonstrations (macroscopic level). The learners were immensely involved in every stage of the lesson. One such episode where all three levels of explanations were vivid, was during the discussion of the electroplating process, see the excerpt below.

Turn	*Speaker*	*Transcription*
85	*Masutha*	*What is happening at your copper metal?*
86	*Lerato*	*Losing electrons.*
87	*Masutha*	*It is losing electrons. That is good. So, I will write copper do not write anything yet, ... (Writing the equation on the board)* $$Cu - 2e^{-} \rightarrow Cu^{2+}$$ *However, they do not want us to write this equation in this manner.*
88	*Martin*	*They want us to take the electrons to the other side*
89	*Masutha*	*Yes. What type of reaction is this where electrons are lost?*
90	*Susan*	*Oxidation.*
91	*Masutha*	*Oxidation, excellent. So, oxidation occurs at the anode. So, can you write the equation am not going to write everything for you?*
92	*Lerato*	*The equation is* $$Cu \rightarrow Cu^{2+} + 2e^{-}$$
93	*Masutha*	*… Let's talk about this … So, who can say what that equation is telling us?*
94	*Clementine*	*Copper atoms are losing two electrons to form* Cu^{2+}.
95	*Masutha*	*Where do these ions go?*
96	*Mary*	*To the Object*
97	*Masutha*	*Object. So, they go into solution to form copper II ions, then to the cathode (object), where they gain electrons to form? Once they gain electrons what do they form?*
98	*Kizito*	*They gain to form a layer of copper at the cathode*

The class was discussing electroplating after a class experimental demonstration by learners. Two learners were involved in the demonstration; they connected the electrolytic circuit and began the experiment with little help from the teacher. A metal ring was connected at the cathode, where brown copper metal was observed courting the ring. Through leading questions from the teacher, (turns 91, 93, 95 and 97) learners were able to write the half-reactions at both the anode and the cathode although the excerpt above only shows the equation at the anode (turn 92). The questions in turns 93, 95 and 97 required learners to explain what was happening at the molecular level. Clementine (turn 94) and Kizito (turn 98) accurately described what was taking place in the electrolytic cell at the two electrodes, the anode and the cathode. The teacher then depicted their explanations with a diagrammatical representation as shown in Figure 7-30 below.

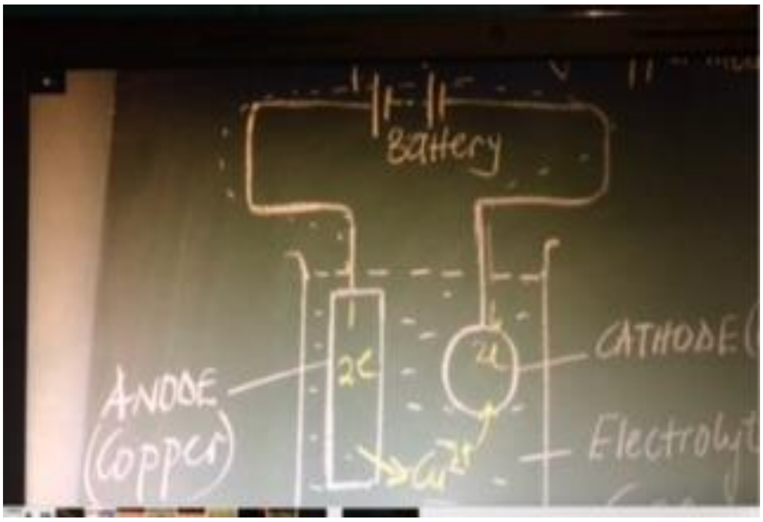


Figure 7.30: Masutha's microscopic representation

Figure 7.30 above depicts the oxidation of copper at the anode which produced two electrons and copper (II) ions. The electrons are shown as 2e going through the external electric circuit to the cathode. The copper (II) ions (Cu^{2+}) once in solution are attracted to the cathode where they receive the electrons to form solid copper metal, and their movement is shown with arrows. The episode clearly illustrates how both learners and the teacher moved among the three levels of explanation of the triangle of levels of thought. Unlike in Mrs Meyer's class where the teacher was the only one who could manage bidirectional movement in all three levels, in Mr Masutha's class it was both learners and the teacher whom simultaneous manoeuvred the three corners of the triangle of levels of thought, as shown Figure 7.31 below.

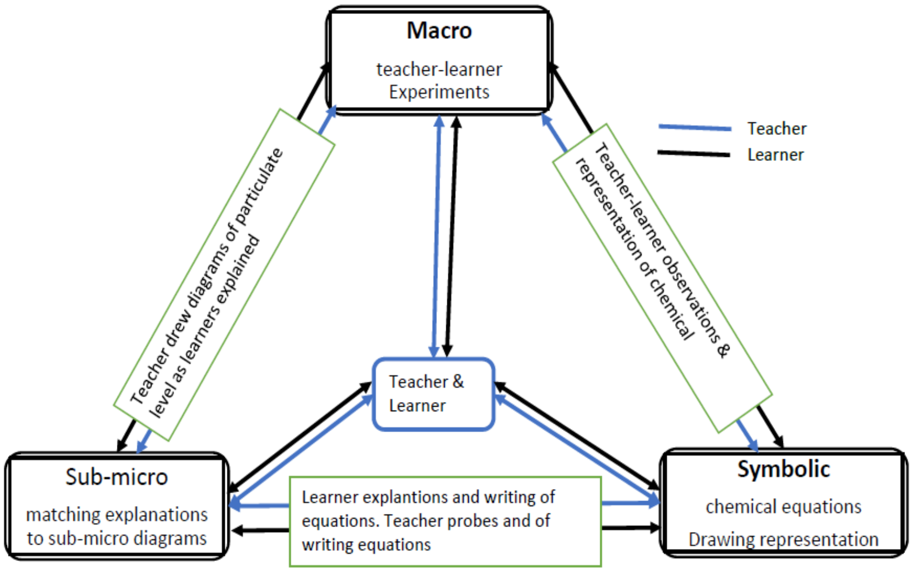


Figure 7.31: The triangle of thought of Mr Masutha

As shown in the diagram above Mr Masutha and his learners dealt with each topic together through class discussions. That enabled both the teacher and learners to move between each pair of the scales of explanation simultaneously. Hence, it can be concluded that all three relations existed in the cognitive structure of the teacher and the learners. However, this can be said to be true only to those learners who were participating in the class discussions. To the silent learners, those who were just observers and note takers the depiction above would only be true once their understanding of the concepts discussed has been assessed per individual.

7.3 Conclusion

This chapter analysed how teachers used two approaches for pedagogical link-making to support knowledge building. The two were modes of representation as well as moving between different scales and levels of representation. I used illustrations from data to describe how teachers used different modes of representations. I found four primary modes of representations which were common among the five teachers. These were mathematical expressions, diagrams, chemical equations and tables. These multiple modes of representations were used to explain and bring about the understanding of the scientific concepts which were under discussion. I found that teachers who used multiple modes of represents in their teaching, facilitated learner conceptualisation of the scientific concepts as learners were observed using those multimodalities effectively. Teachers, who could not utilise a variety of modes of representations relied mainly on verbal discourse and compromised meaningful learning.

Link-making between different scales of representation involves the triangle of levels of thought, which are macroscopic, sub-microscopic and symbolic. The argument made here is that learners must be able to move between each pair of scales for conceptual understanding to be accomplished. Analysis of how teachers used each scale of explanation produced a continuum on the use of the triangle of levels of thought. The one end of the continuum had teachers who only operated on one side of the triangle which was macroscopic and symbolic. In this case, only the teacher used the two scales of explanation. On the other end of the continuum, all three levels of explanation were used by both teachers and learners. In this case, the movement between each scale was bidirectional, that is teachers and learners could move: between macroscopic and symbolic; between sub-microscopic and macroscopic; and between sub-microscopic and symbolic. Two teachers Mr Masutha and Mr Johannes operated at the extreme end where all three levels of explanations or used by both teachers and learners. Mr Zulu and Mrs Ndebele only operated between macroscopic and symbolic levels and could not link macroscopic level to sub-microscopic level and the microscopic level to the symbolic level. Mrs Meyer was found to be in the middle of the continuum where she linked microscopic to macroscopic and symbolic to macroscopic but did not like symbolic level to sub-microscopic level.

CHAPTER 8

Conclusions, Implications and Recommendations

8.0 Introduction

The study followed a qualitative interpretivism paradigm with an epistemological belief that teachers and learners should social construct knowledge. In this chapter, I summarise the findings of this study and how I have answered the three research questions which were being investigated. Further, I articulate the recommendations emanating from the results of the study. The outline of the conclusion chapter follows a unique pattern, different from the usual way of concluding a research thesis. Each research question is concluded separately.

8.1 Research Question 1

To what extent does the Physical Science Document support the progression and coherence of Chemical Change concepts at the FET level?

The first research question dealt with in Chapter 4 looked at the extent to which the Physical Science CAPS curriculum and the work schedule or the annual teaching plan supports the progression and coherence of Chemical Change concepts at the Further Education Training (FET) phase. There were four main findings from the analysis of the documents.

The first finding was that in the topic electrolytic cell (Grade 12) and its central concepts of redox reactions (Grade 11) and reactions in aqueous solution (Grade 10) were sequentially arranged across the grades. The concepts do follow the guides of the spiral approach, hierarchical arrangement of concepts and coherence (Bruner, 2009; Newmann, Smith, Allensworth, & Bryk, 2001). Nevertheless, there were notable omissions of fundamental concepts in Grade 10 and in Grade 11, which gives rise to the second and third findings on this particular research question.

The second finding was the omission of oxidation numbers as a fundamental concept of balancing equation and redox reactions. The DBE foregrounds the use of charges in balancing equations over oxidation numbers. However, for one to understand the transfer of charge between any two species he/she needs to use change in oxidation numbers to determine the amount of charge transferred as argued by Jensen (2009). Leaving out oxidation numbers creates a conceptual gap and does not meet the requirement of the spiral curriculum. A spiral curriculum should begin with essential concepts that are covered at a lower level and revisited in-depth later through mastery of the interrelationship and structure of the vast body of knowledge for conceptual understanding (Bruner, 1960; Grove et al., 2008). Therefore, it is recommended that curriculum developers should take into consideration the inclusion of the concept of oxidation numbers at the lower level of FET (Grade 10).

The third finding from the analysis of the CAPS Physical Science content document was the missing of the concept of electrolytes at Grade 11. The electrolyte concept is superficially covered at Grade 10 when learners investigate the conductivity of solutions. They are required to differentiate good conductors and bad conductors of electricity, which is a good starting point to develop the concept of electrolytes or decomposition of solutions using electric current. However, the concept of electrolytes is not further developed at Grade 11, and the curriculum only requires that it be covered at Grade 12 when learners do examples of electrolysis and its applications. That created a conceptual gap at the Grade 11 level, which could be filled by considering the inclusion of the concept of weak and good electrolytes at this level.

Interlinking of concepts within a grade was the 4th finding of this research on the spiral nature of the CAPS Physical Science content document. I found out that the annual teaching plan (work schedule) which is given to teachers to follow, has disjointed pockets of Chemistry topics across all grades in the FET phase. The topics are separated by Physics topics causing significant gaps between concepts and interfering with conceptual coherence for chemistry.

Eventually, a meso scale that connects concepts separated by days will not be evident in the teaching and learning processes. The lack of meso scale connections hampers a deeper understanding of science where learners are supposed to develop the ability to connect concepts logically (Ausubel, 2012). The importance of meso scale link-making was a significant finding found when investigating the issue raised by the second research question.

Therefore, the curriculum has some critical gaps in Grade 10 and 11 that hamper the conceptual understanding of chemical change at the Grade 12 level. In summary, the absence of oxidation numbers within Grade 10 teaching plan has an effect on the understanding of redox reactions in Grade 11. Similarly, the omission of electrolytes in Grade 11, compromises the conceptual understanding of electrolytic cells in Grade 12. These critical gaps compromise the spirality of the spiral curriculum resulting in content overload at Grade 12 level.

8.2 Research Question 2

To what extent do FET teachers make connections between concepts in developing a scientific story in the teaching of electrolytic cells and its central concepts at the senior secondary level?

The second research question addressed the concepts of continuity by looking at how teachers' practices promoted the development of a scientific story in the teaching of the topic electrolytic cells and its underlying concepts in the FET phase. Three key findings emanating from the analysis of observed lessons and teacher interview are, firstly, there was barely any macro scale link making in the lessons. Secondly, meso scale link-making was the least used by all in the first lesson introducing the topic and, thirdly, micro scale link making was the most used by both teachers and learners.

It was also found that learners made fewer macro scale links than the teachers in the observed lessons. When learners make macro scale links, they make known the nature of previous knowledge they bring within the lesson. Link making at the macro scale helps learners remember or try to connect current ideas with previously learnt concepts in each grade. The importance of prior knowledge in learning is that it brings about the necessary integration of new ideas and prior understanding through making connections between new and old ideas (Ausubel, 2000). The integration of new and old ideas bring about conceptual understanding in the learner.

The absence of macro scale link-making implies that prior knowledge is not fully utilised in the classroom, which compromises conceptual understanding and meaningful learning. When there is no networking of interrelated concepts learners are forced to regurgitate disjointed pockets of knowledge, which culminates in rote learning. According to Newmann et al. (2001) knowledge learnt through rote learning does not remain in memory as it is easily forgotten. Teachers will resort to drilling learners to pass examinations due to incompressible learning of isolated scientific concepts.

The second finding is related to the macro scale results discussed above. Meso scale link-making was the least used by teachers in their opening lessons in each grade across the phase. However, in lesson 2 and 3, the use of macro scale link-making increased. The increase can be attributed to the ability of learners and teachers to relate the concepts of previous lessons (either the first lesson or second lesson or both lessons) to new ideas.

In the first lessons, there were no meso link-making done by both teachers and learners, due to lack of related concepts that were separated by weeks and days. Hence, the teaching of disjointed pockets of concepts brought about by the structure of the annual teaching plan hamper the smooth connections of scientific concepts. The coherent curriculum in which scientific concepts are constructed on one another over a period of time help in supporting learning and enhances meaningful learning (Krajcik et al., 2014). As indicated earlier the separation of chemistry topics with the physics topics in the annual teaching plan did not support the coherence of related concepts in all the three topics that were under investigation in this study. This finding corroborates the findings from the document analysis. Therefore, the implications and recommendations are as alluded in the first research question.

In the third lesson, there was a remarkable increase in the use of meso scale link-making. This remarkable increase was experienced across all grades. It was interesting that even the teachers who used the teacher-centred approach had an increase in linking related concepts within the topic. Teachers who involved learners in the classroom discussions also achieved some learner meso scale link-makings. The concepts covered in the three lessons were interrelated, and learners and teachers were able to identify and link these related concepts, which is the essence of conceptual understanding. Shin et al. (2017) argue that coherent ideas that build upon one another effectively sustain the development of meaningful understanding across time. Consequently, learning of interrelated scientific concepts culminates in conceptual understanding as a result of meaningful learning.

The third finding that was found from making links to promote continuity was that learners easily made links where they were permitted to interact socially, especially with those teachers who promoted group and class discussions. During the group and whole class discussions, learners made relevant link-makings that supported meaningful learning. In this study, although learner social interaction was minimum in most lessons that were observed, where social interaction was implemented learners engaged meaningfully in the classroom discussions. Hence, for learner conceptual understanding to be achieved it recommended that efforts should be created and implemented to enable learner-learner or teacher-learner interactions, through in-service teacher professional development programmes.

One of the reasons why learner-learner and teacher-learner interactions were at a minimum was because of the reduced notion time. I found that not all lessons were contacted in the prescribed time frame as per the timetable. The following are the significant factors that took away teaching and learning time: learner late coming (in all five schools no class started on time); school activities (such as extended assembly times & disciplinary issues); and DBE official visits that asked to address learners within teaching time. During interviews, teachers felt that there was no sufficient time to engage learners in classroom dialogue because the syllabus was congested. I argue that unless the teaching time is recovered from the non-teaching activities, one cannot adequately argue that the syllabus is congested. However, the fact remains that teachers barely engaged learners as they argue that there was not enough time. Hence, there is a need for a study that centres on auditing the time spend in real teaching against that which is recommended by the curriculum developers. Such a study should consider all other administrative issues that are carried out during the teaching time. After that, it can be decided whether the curriculum is over congested or not.

The third finding had to do with micro scale link-making which was utilised by both teachers and learners. The use of micro scale in the teaching and learning process during classroom discussions produced a network of interrelated concepts. Networking of related concepts brings about meaningful learning as teachers and learners revisit previous units in the build-up to the scientific story. Coming back to previously learnt ideas on a regular basis encourages conceptual knowledge (Cullen, 2015). In this study, more links were made in the third lessons than in the first lessons. Teachers and learners made more connections in the third lesson because of the short time frame that separated the concepts and learners could easily remember to connect the ideas taught. However, I found that teachers made links more than the learners in all the three link-makings (macro meso and micro scales) across all grades. Further, I found that learners made more links when there were in small groups and whole class discussions. Where the teacher-centred approach was used, there was no link-making at all by the learners.

The study on pedagogical link-make to support continuity found that both teachers and learners poorly did macro scale and meso scale link-makings in the five schools. The major reason for this finding was due to the incoherent sequencing of the Chemical Change concepts, which were separated by unrelated topics of Physics. On the other hand, the micro scale link-making was fairly done and covered by both teachers and learners in the five schools due to the coherence topics that were covered. However, teachers linked concepts more than learners. In classes where learner social interactions were promoted learners did more linking makings than in those classes where teacher centredness was promoted.

8.3 Research Question 3

To what extent do teachers engage in meaning-making strategies in the teaching of electrolytic cells and its fundamental concepts at the senior secondary level?

Research question three investigated how teachers used different knowledge building pedagogical tools in the teaching of the topic electrolytic cells and its essential concepts at the senior secondary level. Knowledge building requires the formation of conceptual networks between various forms of knowledge in order for learners to develop a conceptual understanding of scientific concepts (Scott et al., 2011). Pedagogical link-making to promote knowledge building has six approaches, but only five were evident in the sample that was investigated. The conclusions, implications and recommendations of the five approaches which were evident in the research are discussed below.

8.3.1 Making links between every day and scientific ways of explaining

The approach of making links between every day and scientific ways of explaining has two pedagogical tools namely, integration and differentiation. Integration is when the everyday meaning of a word has a similar explanation or meaning as the scientific meaning of the same word or idea. Differentiation means that the everyday meaning of a particular idea is not congruent to scientific meaning and explanation of the same concept. Scott *et al.* (2011) assert that the two different explanations can have similarities in how concepts are explained at some point and can possess different explanations of the same concepts in some other instances. I found that the teachers used more integration than differentiation. It was further found that the use of integration and differentiation depended on the teacher's knowledge of the everyday words that need integration or differentiation. Misconceptions about integration or differentiation were uncovered in classes where social interaction was prevalent, and teachers had a chance to address the misconception through class discussions.

When teachers were unaware of the concepts from everyday use that were supposed to be either integrated or differentiated within a science topic, there was no link making done to the learners. If the two ways of explaining are neither integrated nor differentiated, it means that learners' alternative conceptions about scientific phenomena remain unresolved. When the integration and differentiation are made explicit the emergence of misconceptions is reduced (Mortimer & Scott, 2003). If learners are not involved in classroom discussions during the teaching and learning process, it becomes difficult for the teacher to ascertain the prevailing misconceptions in the minds of learners.

Teachers need to be made aware of the scientific and everyday ways of explaining that exist per topic in the curriculum. That is the curriculum developers with the help of subject specialists need to compile a list of everyday words that should either be integrated or differentiated during the teaching and learning process of each topic. Through professional development programmes, teachers should be trained on how to make links between every day and scientific ways of explaining. During such professional development programmes, emphasis must be on the importance of learner engagement. Teachers should also be made aware of the importance of classroom social as such interactions reveal learner's alternative concepts, that should be either integrated or differentiated from the scientific ways of explaining scientific concepts.

3.2.2 Making links between scientific concepts

Analysing the pedagogical tool of link-making between scientific concepts revealed that teachers are quite knowledgeable about linking science concepts. My study shows that teachers do what research has found to be useful, to hierarchical arrangement concepts from simple to complex. It was further found that teachers effectively used well-connected thematic concepts in their explanations. However, not all teachers could engage learners in discussions of these thematic concepts. As a results learner conceptual understanding was compromised as the significant facet (linking science concepts) of meaningful learning would not have been met. Three teaching approaches were found to be prevalent among the participants in the study. These were the teacher-centred approach, a whole class discussion lead by the teacher, and learner group discussion (where the teacher is a facilitator).

The teaching of science requires teachers to present science content as a web of interrelated concepts to learners. In this study, four out of five teachers managed to link the scientific concepts with much understanding of the content knowledge. The emerging conceptual themes were found to have well-connected concepts which were relevant in supporting meaningful learning. Lemke (1990) argues that scientific concepts are never used one at a time; rather their usefulness comes from their interconnectedness to one another. The scientific conceptual themes can be conceptually understood when learners use such themes in explaining or describing a phenomenon in a social classroom setting (Scott et al., 2011). In this study only in once lass of Mr Johannes were learners exhibit an ability to use thematic concepts to explain a scientific phenomenon during learner-learner social classroom interaction. In other classes, such episodes could not be found because learners were not allowed interacting. Therefore, it is recommended that for a deep understanding of scientific concepts to be realised learner-learner interactions should be used regularly in the teaching process.

8.3.3 Making links between scientific explanations and real-world phenomena

The approach of making links between scientific explanations and real-world phenomena is mainly crucial in motivation and maintaining learner interest. Therefore, the teacher should be in a position to do activities that makes the lesson relevant and exciting. In this study, I found that teachers only used experimental activities as their primary source of arousing learner interest in the science classroom. All experimental activities were demonstrations. However, only one teacher allowed learners to have hands-on apparatus during the practical demonstrations. The four other teachers did the experiments themselves while learners observed. The study also showed that one out of five teachers made significant references for everyday chemical phenomena to the scientific concepts under discussion. It was further found that the teacher also involved learners in the discussion of the relevant events.

Therefore on this approach, all teachers but one did not engage in practical activities that could have had a potential of arousing and sustaining learner interest due to the following reasons. For conceptual understanding to take place during practical work, learners should interact with the apparatus themselves, and the teacher remains a guide throughout the activity (Prins et al., 2016). Such practice demonstrated by the teachers who reduced learners to onlooker hinder scientific conceptual understanding. Therefore, teachers should emphasise more on the connectedness of science at school to real life for motivating students to learn science (Cetin-Dindar, 2016).

8.3.4 Making links between modes of representation

The forth pedagogical link-making to promote knowledge building was linking between modes of representations. Among an array of modalities, the participants used extensively four modes of representation. That is mathematical expressions, diagrams, chemical equations and tables. These multi-modalities were widely used to explain and bring about an understanding of the scientific concepts which were under discussion. Teachers who used multiple modalities in their teaching fulfilled the requirements of fostering scientific conceptual knowledge.

In this study, it was found that learners used modes of representation that they have been exposed to by their teachers. Those who were exposed to two modes of representation also used the two modes of representation as well (Mr Zulu's Class). Those learners who were exposed to multimodalities also used the same in their explanations of the scientific phenomena (Mr Johannes' Mrs Ndebele's, and Mrs Meyer's classes). In classes where learners were not given the opportunity to use the modes of representation during the lesson, it was difficult to ascertain whether the use of representations was useful in their conceptual understanding. However, learners who were given the opportunity to discuss showed that they are not sponges of knowledge acquisition. Instead, they are active participants who bring valuable contributions to the scientific knowledge building process. Meaningful construction of scientific knowledge can only happen when learners are given an opportunity to interact with their peers and teachers in a social interaction environment.

McDermott and Hand (2013) assert that each mode of representation is dealt with by a different aspect of the working memory in the learners' brain. When learners are exposed to multiple modalities, there is an integration of the differential cognition leading to conceptual understanding. Learners working with one mode of representation are not in a position to understand abstract science concepts which are made manifest by the use of different modes of representation. Understanding of modes of representation could be difficult if the instructor is not well versed with the multiple modalities. Hence teachers need to be equipped to master and use multimodalities in the teaching of science concepts.

8.3.5 Making links between different scales and levels of explanation

The last form of link-making to promote knowledge building was moving between different scales and levels of representation, which involved macroscopic, sub-microscopic and symbolic. Teachers who used the macroscopic scale were those with excess to equipment and chemicals whereas the sub-microscopic scale was the least used level of explanation. The use of technology (such as laptops, projectors smart boards) is usually an advantage in explaining the sub-microscopic level. However, it was not fully utilised. In contrast, the teachers who did not have that technology were the ones who effectively used sub-microscopic level of explanation, through the use of drawings and diagrams on handouts — those who had technology at their disposal mainly used videos and animations. Two of the participating teachers relied on the narrations provided in the videos or animations and did not explain to the learners the scientific phenomena themselves.

The three scales of explanations are interrelated, and if one is missing or is not covered adequately, it compromises the attainment of conceptual understanding by the learners. However, the sub-microscopic level is the most important one which the teacher should strive to explain to learners. However, it was not the case in this research. When the teacher does not explain the scientific phenomena using the sub-microscopic level, it compromises the attainment of meaningful learning. Johnstone (2000a) argues that the inability to work and think about the chemical phenomena in all three levels concurrently can be the source of several misapprehensions in chemistry that hinder conceptual understanding.

There was a continuum on the use of the triangle of levels of thought. On one end of the continuum all teachers operated on one side of the triangle which was macroscopic and symbolic and on the other end, both teachers and learners were able to use the multilevel of thought simultaneously. Two teachers operated at the extreme end where all three levels of explanations were used by both teachers and learners. One teacher linked two sets of link-making between the levels of explanations which were microscopic to macroscopic and symbolic to macroscopic. Two other teachers only operated between macroscopic and symbolic levels. The teachers could not link the macroscopic level to the sub-microscopic level and the microscopic level to the symbolic level. Learners can acquire disjointed pockets of knowledge when they are not taught to work with the three levels of explanation. Acquisition of disjointed pockets of knowledge can lead to the development of an inaccurate understanding of scientific concepts.

Hence, for learners to be taught at all three levels, simultaneously, the facilitator of such a process should work with all three levels at the same time. From the findings of this research, it is evident that three teachers did not simultaneously work with the three levels of thought (macroscopic sub-microscopic and symbolic levels). When this critical strategy or tool is not used in the teaching of chemistry the ultimate goal of teaching for conceptual understanding is not achieved. Hence, it is recommended that the Department of Basic Education make use of experts from the academic research fraternity in the country to develop teachers in the use of the triangle of levels of thought.

8.4 Recommendations for further research

My research investigated experienced teachers' practices in the teaching of a specific scientific topic and the underlying concepts. Using PLM, it would be interesting also to investigate the practices of the novice teachers especially those who have been subjected to teaching strategies that foster meaningful learning or have been taught about PLM. There is potential for quasi-experimental research as an expansion and deepening of this study. The experimental group would be subjected to teacher professional development concentrating on the pedagogical tools of PLM, whereas the control group is not.

Another area that requires further exploration is the learner assessment. Further research can investigate how teacher practices support meaningful learning and after that assess learner performance in abstract questions after an instruction. Controlled tests could be used.

My research focused on the topic of electrolytic cells. In the research, it was found out that this particular topic was disjointed and not coherent. Therefore, a study on chemistry and also physics topic could be done to compare teacher practices of achieving continuity and coherence in physics and chemistry.

8.6 Conclusion

The focus of my research was why learners have difficulty in answering questions that demand conceptual understanding. My argument, starting from the rationale and introduction, was that assessment of the performance of learners must go beyond their school exit examination results. I deliberately did not investigate learners' performance from Grade 10 because a fair deal of research is into the assessment. Therefore, I choose to investigate if teachers teach for conceptual understanding from the beginning of the phase. I also questioned the CAPS Physical Science content document if it is undoubtedly spiral in nature. That led me to analyse the content document and the annual teaching plan used by the teachers in the teaching and learning process.

Previous studies suggest an array of teaching strategies that foster conceptual understanding through meaningful learning. However, pedagogical link-making was chosen as an analytical tool due to its broadness and that it covers a variety of teaching pedagogical tools. In total, the tool has ten approaches drawn from three forms of pedagogical link-making. The ten approaches have the potential to be divided into more than 20 pedagogical tools depending on how one interprets each approach. However, this research only used two forms, five approaches and 19 pedagogical tools, in analysing teachers' practices.

Using multi-case study qualitative methodology the research generally found that although teachers understand the scientific content knowledge, they lack sufficient skills of knowledge building and continuity that culminates in meaningful learning.

The CAPS Physical Science content document has attributes of a spiral curriculum, but it has some shortcomings which compromise learner conceptual comprehension of abstract scientific concepts.

The amount of content in the curriculum versus the time coverage of the same is not proportional and has pushed teachers to abandon teaching strategies that foster meaningful learning. Hence, teachers whether by design or means of appeasing their superiors have adopted an examination-oriented type of instruction, where they teach to complete the syllabus and drill learners to pass examinations. That lead to my recommendation that the curriculum should be streamlined and the in-service teachers should be supported and equipped with new teaching strategies that foster learner conceptual understanding, through teacher professional development programmes.

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APPENDICES

Appendix A: Ethical Clearance

Wits School of Education

WITS UNIVERSITY

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

01 June 2016

Student Number: 509419

Protocol Number: 2016ECE008D

Dear Brighton Mudadigwa

Application for Ethics Clearance: Doctor of Philosophy

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

Exploring the use of Pedagogical Link-Making as a tool for improvement of practice in the teaching of Chemical Change in South African Classrooms

The committee recently met and I am pleased to inform you that **clearance was granted**. However, there were a few small issues which the committee would appreciate you attending to before embarking on your research.

The following comments were made:

- Specify the length of interviews and training sessions in the Teacher and Principal's letters
- Mention the questionnaire in the Teacher and Principal's letters.
- On the GDE form, include the CAPS document.
- Remember to sign the GDE form (Researcher and the 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,

MMabeta

Wits School of Education

011 717-3416

cc Supervisor: Dr Audrey Msimang

Appendix B: Gauteng Department of Education (GDE) clearances

For administrative use only:
Reference no: D2017 / 105
enquiries: Diane Buntting 011 843 6503

GAUTENG PROVINCE
EDUCATION
REPUBLIC OF SOUTH AFRICA

GDE RESEARCH APPROVAL LETTER

Date:	6 July 2016
Validity of Research Approval:	8 July 2016 to 30 September 2016
Name of Researcher:	Mudadidwa B.
Address of Researcher:	29 Pretorius Street; Noycedale; Nigel; 1491
Telephone / Fax Number/s:	011 739 4601; 083 295 3226
Email address:	bbmudadigwa@gmail.com
Research Topic:	Exploring the use of pedagogical link-making as a tool for improvement of practice in the teaching of Chemical Change in South African classrooms
Number and type of schools:	SIX Secondary Schools
District/s/HO	Gauteng East

Re: Approval in Respect of Request to Conduct Research

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

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

CONDITIONS FOR CONDUCTING RESEARCH IN GDE

1. *The District/Head Office Senior Manager/s concerned, the Principal/s and the chairperson/s of the School Governing Body (SGB) must be presented with a copy of this letter.*
2. *The Researcher will make every effort to obtain the goodwill and co-operation of the GDE District officials, principals, SGBs, teachers, parents and learners involved. Participation is voluntary and additional remuneration will not be paid;*

2016/07/07

1

Making education a societal priority

Office of the Director: Education Research and Knowledge Management ER&KM)
9th Floor, 111 Commissioner Street, Johannesburg, 2001
P.O. Box 7710, Johannesburg, 2000 Tel: (011) 355 0506

3. *Research may only be conducted after school hours so that the normal school programme is not interrupted. The Principal and/or Director must be consulted about an appropriate time when the researcher/s may carry out their research at the sites that they manage.*
4. *Research may only commence from the second week of February and must be concluded by the end of the THIRD quarter of the academic year. If incomplete, an amended Research Approval letter may be requested to conduct research in the following year.*
5. *Items 6 and 7 will not apply to any research effort being undertaken on behalf of the GDE. Such research will have been commissioned and be paid for by the Gauteng Department of Education.*
6. *It is the researcher's responsibility to obtain written consent from the SGB/s; principal/s, educator/s, parents and learners, as applicable, before commencing with research.*
7. *The researcher is responsible for supplying and utilizing his/her own research resources, such as stationery, photocopies, transport, faxes and telephones and should not depend on the goodwill of the institution/s, staff and/or the office/s visited for supplying such resources.*
8. *The names of the GDE officials, schools, principals, parents, teachers and learners that participate in the study may not appear in the research title, report or summary.*
9. *On completion of the study the researcher must supply the Director: Education Research and Knowledge Management, with electronic copies of the Research Report, Thesis, Dissertation as well as a Research Summary (on the GDE Summary template). Failure to submit your Research Report, Thesis, Dissertation and Research Summary on completion of your studies / project – a month after graduation or project completion - may result in permission being withheld from you and your Supervisor in future.*
10. *The researcher may be expected to provide short presentations on the purpose, findings and recommendations of his/her research to both GDE officials and the schools concerned;*
11. *Should the researcher have been involved with research at a school and/or a district/head office level, the Director/s and school/s concerned must also be supplied with a brief summary of the purpose, findings and recommendations of the research study.*

The Gauteng Department of Education wishes you well in this important undertaking and looks forward to examining the findings of your research study.

Kind regards

....

Dr David Makhado

Director: Education Research and Knowledge Management

DATE: 2016/07/07

Office of the Director: Education Research and Knowledge Management ER&KM)
9th Floor, 111 Commissioner Street, Johannesburg, 2001

Appendix C: Consent forms

LETTER TO THE LEARNER

LEARNER SCIENCE EDUCATION PHD RESEARCH THESIS

18 July 2016

Dear Learner

My name is Mudadigwa Brighton, a PhD Student at the University of the Witwatersrand School of Education. I am doing research on:

Exploring the use of Pedagogical Link-Making as a tool for improvement of practice in the teaching of Chemical Change in South African Classrooms

My research involves a study in the area of teaching and learning of science. The research aims at exploring how a teacher makes use of the pedagogical link-making in the teaching of Chemical Change from Grades 10 to 12. The pedagogical link-making approach looks at how the teacher can teach for scientific conceptual understanding using the 3 forms of link making which are, links to support knowledge building, Links to promote continuity and links to encourage emotional engagement. Each linking form has different strategies that a teacher must be cognisant of, prior to teaching a science topic. I will hold a workshop with the teachers on pedagogical link-making and thereafter follow up voluntary teachers in their classrooms and observe them teach particular topics under Chemical Change. The topics are Reactions in aqueous solution Grade 10; Redox Reactions Grade 11 and Electrolytic Cells Grade 12. The teachers will interact with the researcher and discuss how best science can be taught for conceptual understanding using this particular approach.

The specific activities will be to audio and video record all lessons of your teacher teaching your class the topic Reactions in aqueous solution/Redox Reactions/ Electrolytic Cells. In these activities, I will be working with your science teacher(s) as an observer and will not replace or take over your teacher's role. In the research, I will be focusing on how the teacher makes links to the 3 forms of pedagogical link to foster meaning making in science concepts among learners.

I was wondering whether you would mind attending the lessons in question. I also seek your permission to video and audio record the whole of your class and request for your availability and class participation during these lessons.

Remember, this is not a test, it is not for marks, and it is voluntary. If you decide halfway through that you prefer to stop, this is completely your choice and will not affect you negatively in any way.

I will not be using your own name, but I will make one up so no one can identify you. All information about you will be kept confidential in all my writing about the study. All collected information will be stored safely and destroyed within 3-5 years after I have completed my study.

If you are under 18 your parents have also been given an information sheet and consent form.

I look forward to working with you!

Please let me know if you require any further information.

I look forward to your response as soon as is convenient.

Yours sincerely,

____

Mudadigwa Brighton

LETTER TO THE PARENT/GUARDIAN
SCIENCE EDUCATION PHD RESEARCH THESIS

18 July 2016

Dear Parent/Guardian

My name is Mudadigwa Brighton, a PhD Student at the University of the Witwatersrand School of Education. I am doing research on:

Exploring the use of Pedagogical Link-Making as a tool for improvement of practice in the teaching of Chemical Change in South African Classrooms

My research involves a study in the area of teaching and learning of science. The research aims at exploring how a teacher makes use of the pedagogical link-making in the teaching of Chemical Change from Grades 10 to 12. The pedagogical link-making approach looks at how the teacher can teach for scientific conceptual understanding using the 3 forms of link making which are, links to support knowledge building, Links to promote continuity and links to encourage emotional engagement. Each linking form has different strategies that a teacher must be cognisant of, prior to teaching a science topic. I will hold a workshop with the teachers on pedagogical link-making and thereafter follow up voluntary teachers in their classrooms and observe them teach particular topics under Chemical Change. The topics are Reactions in aqueous solution Grade 10; Redox Reactions Grade 11 and Electrolytic Cells Grade 12**.** The teachers will interact with the researcher and discuss how best science can be taught for conceptual understanding using this particular approach.

The specific activities will be to audio and video record all lessons of your child's teacher teaching the topic **Reactions in aqueous solution/Redox Reactions/ Electrolytic Cells**. In these activities, I will be an observer that is I will not replace or take over the teacher's role. In the research, I will be focusing on how the teacher makes links to the 3 forms of pedagogical link to foster meaning making in science concepts among learners
The reason why I have chosen your child's class is because I am doing a research that concerns Physical Sciences Grades 10 to 12 learners at the school your child is attending.

I was wondering whether you would mind to grand your child permission to participate in this project. I further seek your permission to audio and video your child during the lessons in question.

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

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

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

Please let me know if you require any further information.

I look forward to your response as soon as is convenient.

Yours sincerely,

____

Mudadigwa Brighton

INFORMATION SHEET: TEACHERS
SCIENCE EDUCATION PHD RESEARCH THESIS

18 July 2016

Dear Teacher

My name is Mudadigwa Brighton, a PhD Student at the University of the Witwatersrand School of Education. I am doing research on:

Exploring the use of Pedagogical Link-Making as a tool for improvement of practice in the teaching of Chemical Change in South African Classrooms

My research involves a study in the area of teaching and learning of science. The research aims at exploring how a teacher makes use of the pedagogical link-making in the teaching of Chemical Change from Grades 10 to 12. The pedagogical link-making approach looks at how the teacher can teach for scientific conceptual understanding using the 3 forms of link making which are, links to support knowledge building, Links to promote continuity and links to encourage emotional engagement. Each linking form has different strategies that a teacher must be cognisant of, prior to teaching a science topic.

You will be asked to complete a teaching strategy questionnaire, which seeks to ascertain your current science teaching approaches. Prior to a workshop, I request to observe you teaching one or 2 of your lessons under the topic Chemical Change, thereafter I will request to interview you for 30 minutes. The purpose of this observation and interview is to acquaint myself with your current teaching strategies and the nature of your lesson planning. I will hold a workshop with you and other teachers on pedagogical link-making. You and other teachers will interact with the researcher and discuss how best science can be taught for conceptual understanding using this particular approach. The workshop will be done on 17 June 2016 at Stable Inn, Springs from 08:00 hrs to 17:00. Voluntary teachers after the workshops in the third term will be observed teaching particular topics under Chemical Change. The topics are Reactions in aqueous solution Grade 10; Redox Reactions Grade 11 and Electrolytic Cells Grade 12**.**

The specific activities in the classroom will be to audio and video record all lessons of you teaching the topic Reactions in aqueous solution/Redox Reactions/ Electrolytic Cells. In these activities, I will be an observer and will not replace or take over your teaching role. In the research, I will be focusing on how you make links to the 3 forms of pedagogical link-making to foster meaning making in science concepts among learners. I propose to meet you after the observation of lessons for a 30 minute interview to review my observations and your actions in class.

I further request permission to audio and video record you and learners during the lessons in question. I also request that you allow me access to the lesson plans, work schedules and learners' workbooks.

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

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

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

Please let me know if you require any further information.

I look forward to your response as soon as is convenient.

Yours sincerely,

____

Mudadigwa Brighton

LETTER TO THE PRINCIPAL
SCIENCE EDUCATION PHD RESEARCH THESIS

18 July 2016

Dear Principal

My name is Mudadigwa Brighton, a PhD Student at the University of the Witwatersrand School of Education. I am doing research on:

Exploring the use of Pedagogical Link-Making as a tool for improvement of practice in the teaching of Chemical Change in South African Classrooms

My research involves a study in the area of teaching and learning of science. The research aims at exploring how a teacher makes use of the pedagogical link-making in the teaching of Chemical Change from Grades 10 to 12. The pedagogical link-making approach looks at how the teacher can teach for scientific conceptual understanding using the 3 forms of link making which are, links to support knowledge building, Links to promote continuity and links to encourage emotional engagement. Each linking form has different strategies that a teacher must be cognisant of, prior to teaching a science topic.

The teacher will be asked to complete a teaching strategy questionnaire, which seeks to ascertain the teacher's current science teaching approaches. Prior to a workshop, I request to observe the teacher teaching one or 2 of your lessons under the topic Chemical Change, thereafter I will request to interview the teacher for 30 minutes. The purpose of this observation and interview is to acquaint myself with the teacher's current teaching strategies and the nature of his/her lesson plans. I will hold, a one-day workshop with the teachers on pedagogical link-making on the 17^{th} of June 2016. Thereafter I will follow up voluntary teachers in their classrooms and observe them teach particular topics under Chemical Change. The topics are Reactions in aqueous solution Grade 10; Redox Reactions Grade 11 and Electrolytic Cells Grade 12**.** The teachers will interact with the researcher and discuss how best science can be taught for conceptual understanding using this particular approach.

The specific activities will be to audio and video record all lessons of the teacher teaching a **Grade 10/11/12** class on the topic **Reactions in aqueous solution/Redox Reactions/ Electrolytic Cells.** I will be working with your science teacher(s) as an observer that is, I will not replace or take over the teacher's role. In the research, I will be focusing on how the teacher makes links to the 3 forms of pedagogical link to foster meaning making in science concepts among learners. I propose to meet the teacher after lesson observation for a 30 minutes review interview.

The reason why I have chosen your school is that it is convenient to me as I leave within Ekurhuleni East Rand area and I will not travel long distances to other schools from my residential place. I was wondering whether you will permit me to use your school as a research site. I further request permission to audio and video record the teacher and learners during the lessons in question per grade. I also request that you allow me access to the teacher's lesson plans, work schedules and learners' workbooks.

The research participants will not be advantaged or disadvantaged in any way. They will be reassured that they can withdraw their permission at any time during this project without any penalty. There are no foreseeable risks in participating in this study. The participants will not be paid for this study.

The names of the research participants and identity of the school 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 within 3-5 years after completion of the project.

Please let me know if you require any further information.

I look forward to your response as soon as is convenient.

Yours sincerely,

____

Mudadigwa Brighton

Learner Consent Form

Please fill in the reply slip below if you agree to participate in my study called:

Exploring the use of Pedagogical Link-Making as a tool for improvement of practice in the teaching of Chemical Change in South African Classrooms

My name is: ____

Permission to review/collect documents/artefacts	Circle one
I agree that my workbook can be used for this study only.	YES/NO

Permission to observe you in class

I agree to be observed in class.	YES/NO

Permission to be audiotaped

I agree to be audiotaped during the lesson observation	YES/NO
I know that the audiotapes will be used for this project only	YES/NO

Permission to be videotaped

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

Informed Consent

I understand that:

- my name and information will be kept confidential and safe and that my name and the name of my school will not be revealed.
- I do not have to answer every question and can withdraw from the study at any time.
- I can ask not to be audiotaped, photographed and/or videotape
- all the data collected during this study will be destroyed within 3-5 years after completion of my project.

Sign______________________________ Date____________________________

Parent/Guardian Consent Form

Please fill in and return the reply slip below indicating your willingness to allow your child to participate in the research project called:

Exploring the use of Pedagogical Link-Making as a tool for improvement of practice in the teaching of Chemical Change in South African Classrooms

I, ______________________________________the parent of
____

Permission to review/collect documents/artefacts	Circle one
I agree that my child's workbook can be used for this study only.	YES/NO
Permission to observe my child in class	
I agree that my child may be observed in class.	YES/NO
Permission to be audiotaped	
I agree that my child may be audiotaped during the lesson observations.	YES/NO
I know that the audiotapes will be used for this project only	YES/NO
Permission to be videotaped	
I agree my child may be videotaped in class.	YES/NO
I know that the videotapes will be used for this project only.	YES/NO

Informed Consent

I understand that:

- my child's name and information will be kept confidential and safe and that my name and the name of the school will not be revealed.
- he/she does not have to answer every question and can withdraw from the study at any time.
- he/she can ask not to be audiotaped, photographed and/or videotape
- all the data collected during this study will be destroyed within 3-5 years after completion of my project.

Sign______________________________ Date____________________________

Teacher's Consent Form

Please fill in and return the reply slip below indicating your willingness to be a participant in my voluntary research project called:

Exploring the use of Pedagogical Link-Making as a tool for improvement of practice in the teaching of Chemical Change in South African Classrooms

I, ____ give my consent for the following:

Permission to review/collect documents/artefacts	**Circle one**
I agree that my lessons plans, and work schedules can be used for this study only.	YES/NO
I agree that my learners' workbooks can be used for this study only.	YES/NO
Permission to observe you in class	
I agree to be observed in class.	YES/NO
Permission to be audiotaped	
I agree to be audiotaped during the interview or lesson observations	YES/NO
I know that the audiotapes will be used for this project only	YES/NO
Permission to be interviewed	
I would like to be interviewed for this study.	YES/NO
I know that I can stop the interview at any time and don't have to answer all the questions asked.	YES/NO
Permission for questionnaire	
I agree to fill in a questionnaire for this study.	YES/NO
Permission to be videotaped	
I agree to be videotaped in class.	YES/NO
I know that the videotapes will be used for this project only.	YES/NO

Informed Consent

I understand that:

- my name and information will be kept confidential and safe and that my name and the name of my school will not be revealed.
- I do not have to answer every question and can withdraw from the study at any time.
- I can ask not to be audiotaped, photographed and/or videotape
- all the data collected during this study will be destroyed within 3-5 years after completion of my project.

Sign_______________________________ Date_____________________________

Principal's Consent Form

Please fill in and return the reply slip below indicating your willingness to be a participant in my voluntary research project called:

Exploring the use of Pedagogical Link-Making as a tool for improvement of practice in the teaching of Chemical Change in South African Classrooms

I, ____ give my consent for the following:

Permission to use the school as a research site	**Circle one**
I agree that my School can be used for this study only.	YES/NO
Permission to review/collect documents/artefacts	
I agree that my School can be used for this study only.	YES/NO
Permission to observe you in class	
I agree that the teacher and learners can be observed in class.	YES/NO
Permission to be audiotaped	
I agree to the audiotaping during the interview or lesson observation by the researcher	YES/NO
I know that the audiotapes will be used for this project only	YES/NO
Permission to be interviewed	
I agree for the teacher to be interviewed for this study.	YES/NO
Permission to be videotaped	
I agree to the videotaping of participating teacher(s) and learners in class.	YES/NO
I know that the videotapes will be used for this project only.	YES/NO

Informed Consent

I understand that:

- the name and information of the school will be kept confidential and safe and that my name and the name of my school will not be revealed.
- I do not have to answer every question and can withdraw from the study at any time.
- I can ask for the participants not to be audiotaped, or videotape.
- all the data collected during this study will be destroyed within 3-5 years after completion of my project.

Sign_______________________________ Date_____________________________

Appendix D: Interview Protocol

1. The Department of Education claims that the Physical Science content document is spiral in nature. To what extend to you agree with their claim particularly on chemistry?

2. Which topic(s) do you feel should be included or excluded prior to the current grade you are teaching for the following topic Electrolytic cells (12)/Redox reactions (11)/ Reactions in aqueous solutions) ?

3. To what extend does the sequencing of the topics Electrolytic cells (12)/Redox reactions (11)/Reactions in aqueous solutions) foster understanding?

4. What strategies in your teaching do you use to solicit learner prior knowledge?

5. Is learner prior knowledge enough to build new content knowledge on it?

6. Chemistry topics are usually abstract what methods do you use to explain the sub-microscopic level to the learners?

7. Which illustrations do you use to help you explain the sub-microscopic level to the learners?

8. In what ways do you incorporate learner social interaction in your teaching and learning process?

Probing questions

a) Do you always address everyday explanations and scientific ways of explanation on science concepts to help learner understanding?
b) Why do you resent group work discussions?
c) What resources do you use to illustrate behaviour of sub-microscopic particles in your teaching?

Appendix E: Table of frequencies of the 3 levels of explanations as used by each teacher

Teacher	lesson	Macro	Micro	symbolic
Zalechi	1	0	0	3
	2	1	0	4
	3	1	0	4
	Total	**2**	**0**	**11**
Yagwanya	1	9	2	7
	2	8	1	14
	3	4	0	6
	Total	**21**	**3**	**27**
Ndebele	1	0	0	13
	2	0	0	9
	3	3	3	4
	Total	**3**	**3**	**26**
Meyer	1	1	0	13
	2	7	0	6
	3	2	0	11
	Total	**10**	**0**	**30**
Meyer	1	1	0	9
	2	7	4	3
	3	0	2	7
	Total	**8**	**6**	**19**
Musina	1	3	1	6
	2	3	0	8
	3	3	5	4
	Total	**9**	**6**	**18**
Grand Total		**15**	**11**	**30**

Appendix F: Supporting Argumentation in Chemistry Education in Low-income Contexts: Book chapter published with the Royal Society of Chemistry

ROYAL SOCIETY OF CHEMISTRY

Proofing your Book Chapter

The following contains the PDF proof of your book chapter for you to review. Please follow the steps below to proof your chapter.

1. Read through your chapter carefully

- Remember to check that:
  - special characters appear correctly, especially in equations
  - Figures and Tables are correct
  - headings and sub-headings are placed correctly
- Our staff will not read through your chapter in detail once you have returned it, so please make sure you have checked everything. Final responsibility for content lies with the author.
- As no revised proofs will be provided, please ensure all required corrections are indicated at this stage.

2. Mark up any corrections that are required

- Please only correct scientific or grammatical errors in your chapter – **do not** rewrite sections or make minor cosmetic changes at this stage.
- Please use the **annotation tools** to mark up corrections on the PDF proof – further instructions can be found on the following page.
- Please do not edit the PDF directly or send a list of corrections.
- If any replacement figures are required, please resupply the file at the highest possible resolution
- Please **only supply new versions of figures if you have been requested to do so, or you need to supply a corrected version.**
- Permission statements for reproduced material may have been edited to meet the different requirements of the copyright holders. Please do not correct the formatting of these statements

3. Make sure you have answered all author queries

- These are listed before the beginning of the chapter – click on the query number to jump to the relevant place in the text.
- **Please put your responses in the text, not on the query page.**

4. Return your corrected proof to your editor(s)

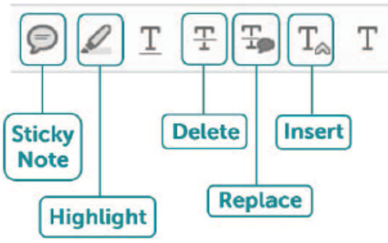
- Please email the annotated PDF of your chapter to sibel.erduran@education.ox.ac.uk within **ONE WEEK** of receipt.
- Please do not return the PDF to Books Production, or to the email address from which you received the download link.

If you have any queries, please do not hesitate to contact us at booksprod@rsc.org

How to Annotate your PDF Proof

Note: The location and appearance of tools may vary depending on the software you are using to read your proof. We recommend using Adobe Acrobat Reader DC (as shown in the screenshots below), which can be downloaded for free online.

The **Comment** function can be found in the **right-hand sidebar**, which should appear when you open your PDF. Otherwise, click '**Tools**' and then select '**Comment**'. This will make the **Comment tools** visible (shown below).



Select the piece of text that you want to mark up, and then click on the relevant Tool button to add the mark up to the text.

For the Insert, Replace, and Sticky Note tools, this will open up a Note in which you can add instructions, or the text to be replaced/inserted – otherwise, you can double-click on the mark-up to open this.

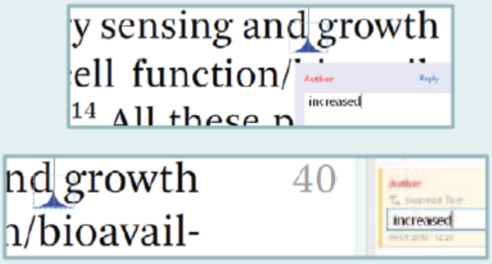
For all tools, any instructions you've added will appear in the Comment sidebar – you can also double-click on this to change, add to or remove the instructions.

Replace

Use the Replace tool to indicate text that should be changed.

Insert

Use the Insert tool to provide new text.

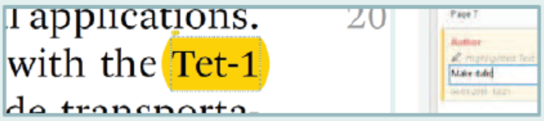


Delete

Use the Delete tool to indicate text that needs to be removed completely.

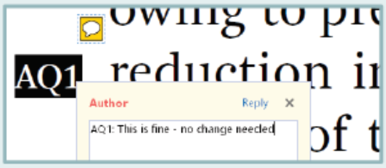
Highlight

Use the Highlight tool to indicate formatting changes to text.



Sticky Note

Use the Sticky Note tool to respond to a query, or indicate a change that cannot be marked up using one of the tools above.



Hints and tips

Special characters can be pasted into corrections from the Character Map in your operating system.

Text can be made **bold** and **italic** using shortcut keys Ctrl+B and Ctrl+I.

If you have difficulty selecting all the text you wish to correct, try holding down the Shift key and using the arrow keys.

AUTHOR QUERY FORM

Book Title: Argumentation in Chemistry Education: Research, Policy and Practice
Chapter 12

Please indicate the changes required in response to the queries within the text. If no changes are needed please clearly state this next to the query marker.

AQ1 The number of sub-heading '12.7.2 Shared Understanding of Goals and Working with Learner Language' has been changed. Please check that this is correct.

AQ2 Ref. 13: Please provide the page (or article) number(s).

Abstract

The abstract for your chapter is reproduced below for your reference. Please note that this will **not** appear in the final printed version of your chapter.

In this chapter we make the argument that argumentation is a high level form of engagement which is difficult to establish, support or sustain, particularly in constrained teaching and learning contexts such as prevail in many South African science classrooms. The South African education context is as diverse as the country's general population in terms of social, economic, cultural and linguistic differences. This diversity is partly responsible for the persistent disparate learner experiences in spite of huge government efforts towards equitable provision of education since 1994. Some of the challenges include resourcing of schools, inadequate infrastructure (large classes and crowded classrooms), teacher provision and/or preparation, learner preparedness for the grade level and poverty. Also, for various social and political reasons science is taught and learnt in English in spite of generally low learner proficiency. Using vignettes from real classroom interactions we illustrate how argumentation plays out in some chemistry classrooms. We demonstrate teacher and learner engagement in argumentation in ways that have not been reported elsewhere, both in whole class and small group discussions; how teacher questioning and response to learners' ideas, making the rules of engagement and paying attention to language facilitated argumentation in these classrooms.

CHAPTER 12

Supporting Argumentation in Chemistry Education in Low-income Contexts

A. MSIMANGA* AND B. MUDADIGWA

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Parktown, Johannesburg 2193, South Africa
*Email: audrey.msimanga@wits.ac.za

12.1 Introduction

Argumentation is a high level form of engagement which is difficult to establish, support or sustain in constrained teaching and learning contexts such as prevail in many South African science classrooms – contexts of poor school resourcing, inadequate infrastructure (large classes and crowded classrooms), inadequate teacher provision and/or preparation, learner under preparedness for the grade level, poverty and hunger as well as teaching and learning science in a language that learners and some teachers are not proficient in. In order for argumentation to happen learners need to be talking and all the factors listed here militate against meaningful classroom talk.

However, our research has revealed some teacher pedagogical practices that are specific to the context. We have watched teacher efforts to get learners who previously would not talk at all to engage in argumentation in ways that have not been reported elsewhere. We recorded collaborative teacher–learner argument construction in whole class discourse and argumentation in small groups in learners' home languages. We concluded that

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Edited by Sibel Erduran

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the following are some of the strategies that work in these classrooms and we illustrate these through vignettes from selected classrooms:

- Teacher questioning and teacher response to learner ideas.[1] Similar to Traver (1998) we observed that learner engagement was dependent on the kinds of questions the teacher asked. Also, the teachers' F-move was important in opening up or shutting down learner argumentation depending on whether it was elaborative or evaluative according to Virri and Saari's categorisation of teacher feedback.[2]
- Enabling a shared understanding of goals of the task or activity including mobilising the language resources of the classroom. Here we illustrate how learner engagement in chemistry classrooms can go beyond Jimenez-Aleixandre "doing the lesson" towards "doing the science"[3] if they have a shared understanding of the goal of the activity. In South Africa, English is the preferred language of instruction, yet most learners (and some teachers) are not proficient in the English language. Successful chemistry teachers therefore, tend to pay attention to language matters in their teaching, explicitly mobilising the language resources of the classroom.

We begin with a brief recap on the role of argumentation in science teaching and learning and then go on to discuss low-income teaching and learning environments and the South African context, leading to a discussion of the challenges of working with argumentation in these atypical low-income contexts. Our main argument is that the combination of historical, political, cultural, linguistic and socio-economic state of the South African education system makes it unique, complex and atypical. Thus supporting argumentation in these contexts should begin with supporting teacher and learner orientation to classroom talk and forms of interaction that open up the classroom as a space for a genuine give and take with shared understandings of the goals of classroom interaction. The challenges of creating the requisite dialogic discourse in such classrooms are discussed with reference to vignettes from some South African classroom to illustrate how teachers take up and adapt argumentation for their contexts.

12.2 The South African Context

South Africa is hardly a typical example of a low-income context. According to the June 2017 World Bank list of economies, South Africa is in the upper middle-income category. Low-income economies were defined as those with a gross national income per capita of $1005 or less in 2016; lower-middle income economies were between $1006 and $3955 while upper middle-income economies like South Africa were at $3956–$12 235 per capita.[4] However, research shows that South Africa's upper middle-income status does not translate into social and economic benefit for all its citizens. For instance, Van der Berg argued that South Africa's social indicators like life expectancy, infant mortality and quality of education are closer to those of lower-middle income and even low-income countries and that in fact South Africa's social inequality is on the rise.[5] Education research further indicates that these inequalities are mirrored in education. According to Spaull[6] "South Africa has the worst education system of all middle-income countries . . . (and) perform(s) worse than many low-income African countries." Spaull[7] further argues that "The strong legacy of apartheid and the consequent correlation between education and wealth have meant that, generally speaking, poorer South African students perform worse academically" (p. 436). According to Spaull the South African primary school comprises "two different education systems. . . one which is functional, wealthy, and able to educate students; with the other being poor, dysfunctional, and unable to equip students with the necessary numeracy and literacy skills they should be acquiring." Thus, any thinking and/or planning for teaching and learning and resourcing should take these inequalities into account.

This diversity and complexity of the South African education system creates a similarly diverse and complex range of classroom contexts, from the well-resourced schools in affluent communities to poor schools in townships and informal settlements and down to some rural schools with almost non-existent infrastructure. South African schools are categorised according to the quintile system, a system of ranking schools according to their infrastructure in order to systematically improve equity in education.[8] Quintile 1, 2 and 3 schools cater for learners in the poorest neighbourhoods while Quintile 4 and 5 schools are located among the more affluent communities. The quintile system was conceived as a way of addressing the diversity and inequality of schooling and classroom environments. Government funding is apportioned according to Quintiles. Thus, Quintile 1 schools are the poorest 20% of schools and receive the highest allocation per learner, while Quintile 2 caters for the next poorest 20% of schools and Quintile 5 schools represent the most affluent schools and receives the lowest government funding. Unfortunately, in science as in other subjects, it is also a reflection of the vast differences in learning experiences. Learner performance and achievement at the exit level national examinations still mirror the quintile categories and tend to follow racial and socio-economic trends.[3] Learners in low socio-economic contexts still perform the worst and many are unable to proceed with any form of education beyond the 12th Grade.

The vignettes cited in this chapter are from classrooms in Quintile 1–3 schools serving township communities. There is considerable internal variation among this group of schools in terms of resourcing, teacher and learner attributes as well as learner preparation for the grade level. The teaching and learning of science is similarly context dependent and varies among the Quintile 1–3 schools. There is a much higher demand on science teachers in these contexts to draw on a variety of teaching strategies in order to be able to create appropriate learning opportunities for the diversity of learners in their classrooms. All of this is against a back drop of generally low performance in science in South Africa. For instance for the years 2016 and 2017 only 39.5% and 42.2% of the Grade 12 candidates performed above 40% level in the National Senior Certificate examinations, respectively.

12.3 The South African Chemistry Curriculum Context

In South Africa science is compulsory for all learners up to the 9th Year of schooling. At the Senior Phase, Grades 7–9, the curriculum provision is Natural Sciences (NS) which is seen as serving "a dual purpose: it must enable learners to make sense of the world in scientific terms and prepare learners for continuing with a science(s) into the Further Education and Training (FET) phase… and beyond"[9] (p. 7). The NS curriculum covers the Physical Sciences, Life Sciences and Earth Sciences as a broad introduction to the specialisations later in the FET Phase at Grades 10–12. The NS curriculum specifies four knowledge areas: Life and Living (which leads to Life Sciences in the FET); Matter and Materials (which leads to Physical Sciences in the FET); Energy and Change (which leads to aspects of both Life Sciences and Physical Sciences); and Earth and Beyond (which leads to both Life Sciences and Geography). At this level NS teaching should promote and develop scientific literacy in all learners with the recognition that some may not continue with science subjects beyond Grade 9.

At the FET level the science curriculum is organised in the subjects, Life Sciences and Physical Sciences. The Physical Sciences covers both physics and chemistry content in six main knowledge areas, three in chemistry: matter and materials; chemical change; and chemical systems as well as three in physics: mechanics; waves, sound and light; and electricity and magnetism. The South African science curriculum emphasises the inclusion of Indigenous Knowledge Systems (IKS) in the teaching of science with a view to develop in learners the ability to draw critically from multiple worldviews in understand the physical environment.[10,11]

The Physical Sciences curriculum document advocates a spiral approach in the teaching of the science content, in which concepts are introduced in the lower grades and gradually built upon and interlinked progressively with other concepts in successive higher grades.[11] However, in spite of this envisaged connectedness in concept coverage, the Department of Basic Education's annual diagnostic reports continue to show poor learner performance at Grade 12 in questions that require an understanding of basic concepts and linking to concepts covered in higher grades.[12] In another publication we examine this curricular claim for the spiral approach in coverage of chemistry concepts at the FET level. We look at the extent to which the curriculum is comprehensible and progressional in the organisation of concepts and the teaching of electrolytic cells at the FET phase. We argue that there is a mismatch between the curricular aim for a spiral approach and how the concepts are arranged in the curriculum document according to grades which makes it difficult for teaching to take the envisaged spiral approach[13] (in pr In this chapter however, we assume the curricular objective of progressive coverage of chemistry concepts and only focus on how teachers employ argumentation in teaching the chemistry content in the classrooms observed. In particular we focus on contextual issues such as how teachers work with the diversity of learners in South African science classrooms or how IKS might be related to the chemistry curriculum.

In an earlier study Erduran and Msimanga[14] pointed out the unique positioning of argumentation in the South African curriculum context alongside other themes such as IKS. According to Ogunniyi[15] "IKS reflects the wisdom about the environment developed over centuries by the inhabitants of South Africa, and much of this valuable wisdom believed to have been lost in the past 300 years of colonization now needs to be rediscovered and utilized to improve the quality of life of all South Africans." Erduran and Msimanga (2014) noted that other curricula around the world did not conjointly promote the acquisition of IKS within the science curriculum. Thus, the South African curriculum aims to incorporate IKS in science teaching, while also promoting evidence-based reasoning through Nature of Science (NoS) and argumentation. The authors also noted the tensions arising from this curricular decision in terms of the professional development of teachers. Teachers are expected to be able to decide on the appropriate content and pedagogical approaches to use to meet these curriculum objectives. Erduran and Msimanga argue that this requires a high level of teacher subject matter knowledge and confidence, a task which not all South African science teachers are adequately prepared to perform. Argumentation in itself is viewed as a higher-order thinking skill that places significant demands on teachers.

12.4 The Role of Argumentation

The role and importance of argumentation in the teaching and learning of science has been researched extensively internationally and recently in South Africa as well. Arguments are critical for development of epistemological knowledge of the discipline, they facilitate knowledge construction and participation in a dialectical process of critiquing and warranting of claims, whether one's own or others' claims. Thus, argumentation is implicated in the development of learner scientific reasoning and learner conceptual understanding.[16–18] Argumentation is also important in enculturation of learners into the practices of scientists.[19,20] Argumentation is seen to be at the core of science teaching and learning:

> "Argument – justification of claims with evidence – is not a peripheral aspect of science; it operates at the heart of science... Without a chance for pupils to talk to each other, without the space to debate and communicate their ideas, it is difficult to see how they can learn any concepts, let alone the discourse of science" (p. 29)[21]

Argumentation has therefore been the subject of much research as a teaching strategy for stimulating learner participation in structured discussion and as a tool for knowledge construction in science classrooms around the world. Hence argumentation can be regarded as an important form of knowledge to be taught to science learners (the skills, norms and values in the use of evidence to support claims) as well as an important part of the teaching processes.[22] In this chapter we discuss both the role of argumentation as a tool to foster learner participation and engagement and its role in the meaning-making process. Other studies have looked at curricula and pedagogical implications of argumentation.[23,24] Berland and colleagues demonstrated the importance of understanding the goals of argumentation; thus understanding the differences in argumentation for sense-making, for articulating understanding and for persuading others of these understandings. An understanding of these goals of argumentation had implications for teacher decisions in the design and implementation of instructional interventions to support student argumentation and conceptual understanding.

Also important is the work of Sampson and Clark on the value of collaborative argumentation in small groups, the impact of collaboration on scientific argumentation.[25] High school chemistry students were observed to be able to construct arguments in groups more easily than individually. Collaboration during argumentation in small groups enhanced individual student learning. Furthermore, Sampson and Clark (2008) explored the efficacy of argumentation as a research tool and argued that it should be viewed as a tool that can be adapted for different contexts and/or goals.[26] They argued for research beyond micro-analysis of structure of student arguments to research to understand the interaction of "structural, conceptual, epistemic, and social aspects of argument generation" and the "underlying reasons for these patterns" (pp. 469–470). Recent argumentation research in South Africa is exploring these intricate interactions.

12.5 Argumentation in the South African Context

Argumentation research in South Africa is still emergent, having established here only in the last decade. Most of the research has focused on the potential for argumentation in South Africa's curriculum change context. The South African curriculum has undergone several iterations of change and revision, from an outcomes focus with loose framing of the content knowledge to be covered to the current strongly framed content-heavy Curriculum and Assessment Policy Statement (CAPS).[27] As already noted in the previous section, in its outcomes-based era the science curriculum required the inclusion of indigenous knowledge in science teaching. In that phase, argumentation research then linked closely to research on the NoS and the Nature of Indigenous Knowledge Systems (NoIKS). For example, Ogunniyi proposed the Contiguity Argumentation Theory or CAT, an adaptation of Toulmin's model TAP for exploring the interface between different thought systems – in this case science and IKS.[28] Ogunniyi argues that when confronted with counter-intuitive school science learners are exposed to five possible types of adaptive co-existence: the dominant, suppressed, assimilated, emergent and equipollent situations. In the dominant state the underlying assumptions of one thought system are amenable to the teaching and learning context while in the other states the one system is either suppressed by or assimilated into the other in the face of compelling evidence. Then in the emergent state the learner is confronted by a concept for which s/he does not have pre-existing schema and in that case new ones are formed. Finally, in the equipollent state two competing schema exist as parallel notions of the concept. Ogunniyi's argument is that a variety of possible interactions can be expected when argumentation activities are used in South African classrooms particularly in conjunction with IKS.

Other argumentation work in South Africa has focused on development of practicing science teachers' argumentation skills. Scholtz and her colleagues for instance were concerned with understanding the nature of interaction in small group discussions using the TAP model in the context of continuous professional development programmes.[29,30] They reported a unique style of argumentation which precluded rebuttals, which they named inclusive argumentation. Teacher disagreements were either in the form of an affirmative statement followed by a counter claim or alternative warrant, or they were phrased as a question. This form of engagement was explained in terms of the concept of *Ubuntu. Ubuntu* is a way of talking in the African cultural context based on a world-view that emphasises consideration for the other person, "instead of comparing and judging individual contributions on their intrinsic merit, contributions are judged in terms of the extent to which they promote harmony and reciprocity"[31] (p. 31). Rebuttals were used differently from the Toulmin's argument structure as participants softened the challenge, as it were, in an effort to promote this harmony and reciprocity. Both the Ogunniyi and Scholtz research involved adult participants. Recent work on argumentation in South Africa has focused on more adult–child and child–child or teacher–learner and learner–learner classroom interactions.[32]

Previous argumentation research in South Africa focused on small group discussions by largely bilingual teachers and student teachers in the Cape Province of South Africa. Argumentation research with younger learners in the more linguistically diverse Gauteng Province, particularly in township schools, has come up with forms of argumentation unique to multi-lingual contexts. For instance, hybrid forms of engagement were observed as teachers adopted pedagogical strategies that required previously silent learners to engage in classroom talk. Instead of using the traditional argumentation activities that require learners to engage with each other and support their thinking among themselves, teachers were observed modelling argumentation in whole class interaction. As teachers changed the kinds of questions they asked and the forms of feedback that they gave in response to learner answers, learners started talking and engaging each other about the science content. Interactions transformed from teacher–learner 1, teacher–learner 2 to triadic teacher–learner 1–learner 2 forms. Eventually, the teacher and learners were engaging in collaborative argumentation. Ultimately as learner talk became entrenched and teachers started using tasks designed to promote small group discussions another unique form of argumentation was observed. Learners were observed to immediately switch to their home language, using the more familiar language to make sense of the science and to challenge each other in small group discussions.[33]

The emergence of these contextual forms of engagement; inclusive argumentation, contiguity argumentation, collaborative argumentation, argumentation in home languages all attest to the potential for adaptations of argumentation in South African contexts.[34] The study of argumentation in South African classrooms is dependent on transformation of classroom discourse from interaction dominated by teacher talk to classrooms where learners are actually talking in class. Thus, for the most part, supporting argumentation in these contexts is about developing dialogic discourses in the science classrooms – helping teachers to get their learners talking.

12.6 Development of Dialogic Discourse – How to Get Learners Talking and Arguing

Literature emphasises the importance of whole class discussion to develop learner ability to dialogue.[35,36] According to Roth, whole class discussions are just as important as small group discussions in providing opportunities for developing interactive classroom discourse. Teacher and peer questions, comments, and suggestions help to sustain the conversations. These kinds of conversations have the potential to break the barrier between formal classroom discourse, formal science and learner personal experience, providing for Aikenhead and Jegede's idea of learner navigation of borders between the different sub-cultures that they belong to.[37] In the South African context this would include border crossing between formal science and IK and between the language domains.

According to Yackel dialogic discourse results from the negotiation of social roles which have to be taken-as-shared, in other words intersubjectivity between the teacher and learners and also among the learners.[38] This happens as the teacher validates, suppresses, recognises, reiterates, clarifies, acknowledges and emphasises learner ideas and involving as many learners as possible in the co-construction of arguments (explaining and justifying own thinking). Among learners this intersubjectivity happens through inclusiveness, asking questions, and challenging each other's ideas. According to Driver and Newton (2000) it is also important for participants to be awareness of the norms of engagement.

However, establishing the desired dialogic discourse in the science classroom is not easy, particularly where learning happens in a foreign language. Learners are not able to engage confidently in classroom talk, much less construct scientific arguments. Rojas-Drummond and Zapata[39] describe a dual demand on learners to build the requisite registers for the language of instruction as well as engage in the meaning-making processes of the discussion. Learner engagement in their natural languages seems to mediate the dual demand on learners, facilitating easier engagement in the meaning-making process. However, following small group discussions learners are usually required to report back to the rest of the class or present their work in writing in English. This introduces different demands on learners to make the transition from meaning-making in their own language to articulation of their understanding in English. Supporting argumentation in these classrooms can sometimes mean a choice between investing in the emerging learner talk and focusing on developing learner argumentation skills. For many South African learners acquainted with traditional teaching methods this shift to interactive methods that requires them to participate in classroom discussions is not easy. The vignettes discussed in the next section illustrate some of the interaction observed in chemistry lessons and how the teachers supported development of learner argumentation skills.

12.7 Illustrating Argumentation in South African Chemistry Classrooms

We observed teacher efforts to get learners talking in these classrooms and learners ultimately began to engage in argumentation in various ways. Two key forms of teacher support merged; creating an environment conducive to learner talk, and mediating language transitions. The first vignette illustrates how one teacher's questions and the kind of feedback that she gave in response to learners' contributions created opportunities for learner engagement in classroom discussion and argumentation.

12.7.1 Teacher Questioning and Responses to Learner Contributions

The following excerpts are taken from my other published work.[33,40] The first is from Msimanga and Lelliott (2014) (pp. 195–200) and the second is from Msimanga (2013) (pp. 192–206).

The vignettes in this section illustrate co-constructed argumentation between a teacher and her chemistry class talking about chemical bonding. The events presented here happened in the middle of the lesson around an error that became apparent when a learner responded to a teacher question. The teacher asked what would happen when two atoms involved in formation of a covalent bond drew closer together as their potential energy decreased. The learner Tahari answered that "*the atoms are now going to be negatively charged*". Instead of simply ignoring the incorrect answer and asking another learner as she would normally do, the teacher actually engaged the class in a question and answer session to address the error. We focus here on the questions that she asked and how she worked with the learners' responses to her questions, resulting in a previously unplanned for collaborative argumentation episode. The utterances are transcribed verbatim in the language that they were made in (in italics) and translated into English (Table 12.1).

The transcripts open with the teacher posing a thinking question '*What do you think is going to happen?*' to which Tahari answers '*. . .they are now going to be negatively charged.*' The teacher's '*Why?*' seemed to be a genuine reaction to an unexpected or even surprising learner answer. This is borne out in the teacher's follow up question when it becomes clear from Tahari's answer in turn 117 that she is articulating a deep misunderstanding, perhaps even misconception. Tahari supported her claim that the two atoms will become negatively charged as a result of moving closer to each other with the evidence that '*they are about to come together*' warranted by the assertion that, '*they are attracting each other.*' Normally, this teacher would have simply ignored the error, directed the original question to another learner and kept going until she got the correct answer or provided the answer herself. This she said "saved time'' and got the class back on task. In this instance however, she decided to pursue the error, inviting other learners to, as it were, interrogate their peer's thinking. By the end of the episode eleven learners had spoken and participated in resolving the error. It could be argued that the teacher facilitated and mediated shared meaning making by more than just the one learner.

It also became clear as the teacher continued to question them that Tahari's error was shared by other learners as well. According to Berland and Reiser (2009) in sense-making argumentation the aim is to get learners to open up to their peers' ideas and in the process enable them to modify their own understanding. We see this in the next excerpt as the teacher continued her line of questioning with another learner, Vuma who joined the argument to articulate his own (erroneous) understanding (Table 12.2).

Vuma seemed to agree with Tahari's claim but on different grounds. Tahari warranted her claim on the nature of forces operating between the atoms as the distance between them decreases; Vuma, on the other hand, premised his argument on evidence about covalent bonds (turn 124). Of course, this new argument did not bring the class any closer to resolving the problem but it helped reveal more learner erroneous thinking. The teacher's response at the beginning of the next excerpt below '*When does an atom*

Table 12.1 Turns 114–118, transcript of bond energy lesson.

114	Teacher	If they move closer to one another this means that the distance between them decreases. What do you think is going to happen?
115	Tahari	Er if they decrease they are now going to be negatively charged
116	Teacher	Why?
117	Tahari	Ma'am because now they are attracting each other Ma'am *Angithi manje sezahlangana sezifunukuhlangana* (they are now just about to come together)
118	Teacher	(*addressing the rest of the class*) What do you think of that statement?

Table 12.4 Turns 184–185 (transcript of bond energy lesson).

184	Bonga	I don't think of any er er negative charge forming coz we are dealing with covalent bonding here (inaudible) they share their electrons with each other so I think negatively charged electrons only form when you are dealing with ionic bonding
185	Class	Yes yes

managed to work with learner contributions in ways that opened up the classroom space for learner talk and argumentation. The difficulty for the teacher in this case is finding the balance between allowing the engagement to continue sufficiently to facilitate learner conceptual understanding and moving the lesson ahead, thus shutting down and opening up dialogic engagement in the lesson.

The teacher did in fact shut down the dialogic engagement at this point and proceeded to ask some guiding questions that led the class to the correct answer. At the end of the episode one learner who had been silent throughout the discussion raised his hand to make an unsolicited contribution (Table 12.4).

This raises the question of how participation is defined in this context. What can one conclude about of the level of participation when only eleven out of more than fifty learners in the class engage in the 15-minute episode of teacher–learner talk? Are the other forty participating? If so what is the nature of their participation? Are they engaging in silent personal argumentation and like Bonga are they able to ultimately construct and support correct arguments in the end? How would a teacher know if she is supporting argumentation for all?

In the next set of vignettes we demonstrate how argumentation played out in another chemistry class during small group discussions in ways that speak to the current debates on the role of language in multi-lingual science classrooms. In South Africa the debate is mainly about the challenge of teaching and learning science in English, a language that most learners are not proficient in while attempting to prepare learners for final assessment (and national examinations) in the English language.

The vignettes are used to illustrate how learners created for themselves safe spaces to draw on their linguistic capital, using their own home languages to engage with the science concepts for meaning-making and conceptual understanding. They then have to negotiate the border crossing back to the language of instruction as they articulated these understandings in their reports in English to the whole class.

12.7.2 Shared Understanding of Goals and Working with Learner Language

Some of the data cited here is published in Msimanga and Lelliott 2014, pp. 1159–1183.

Table 12.2 Turns 121–126, transcript of bond energy lesson.

121	Teacher	She says that if they come closer the hydrogen is going to become negative because of the attraction force. What do you think about that?
122	Vuma	Er Ma'am I much agree
123	Teacher	Oh you agree?
124	Vuma	Yes Ma'am coz Ma'am when they bond covalently they are bonding to achieve the nearest noble gas
125	Class	Yes
126	Vuma	Ok fine then so soon as they reach the noble the nearest noble gas they share and then when they are sharing, er, they become negatively charged

Table 12.3 Turns 151–164, transcript of bond energy lesson.

151	Teacher	When does an atom become negatively charged?
152	Teacher	Let me give you a chance
153	Thinta	Ma'am I disagree with the statement coz Ma'am I think when the two atoms (inaudible) the chemical potential energy will increase
154	Teacher	Why do you disagree with the statement?
155	Thinta	It's because Ma'am when the two atoms interact it's impossible for them to be negatively charged
156	Tahari	Ma'am didn't you say...?
157	Teacher	Why?
158	Thinta	*Azikathintani* Ma'am (they are not yet touching)
159	Class	Yes yes yes
160	Tahari	Ma'am didn't you say when they er when they get closer to each other when they attract each other the potential energy it will decrease
161	Thinta	It's like this... (*holding pen and set square I each hand and moving them towards each other*)
162	Tahari	It will decrease...
163	Thinta	*Azikathintani* (they are not yet touching)
164	Tahari	Ma'am you said you said the potential energy will decrease and therefore those atoms are going to be negatively charged

become negatively charged?' Seems to suggest that she had identified the root of the learners' misunderstanding – the circumstances under which an atom becomes negatively charged.

Of particular interest to us is how the teacher maintains the cognitive demand of the task and does not simplify the question as the discussion unfolds. Research in mathematics classrooms in South Africa indicates that in many cases as the teacher senses that her learners are struggling to get to the correct answer there is a tendency to then ask simpler questions thus reducing the cognitive demand of the task at hand.[41] In this case the teacher asked the question differently but without reducing its difficulty and so maintained the cognitive demand of the task.

What was also interesting was how as the discussion continued, learners started responding more directly to each other's ideas rather than focusing on answering or responding to the teacher's question, thus rebutting each other's claims directly – turns 160–164 (Table 12.3). The teacher had

We present vignettes from a chemistry lesson on reactions of acids and bases. This teacher used small group tasks quite frequently in her classroom with learners in self-selected groups of four and five. We noted that learners always deliberately sought out the same members each time to form the groups. We learnt later that these were not only friendship groups, but that learners selected those who share similar home languages. The utterances are in the language in which they were made (in italics) with English translation. We present data from one of the small groups.

The task was to determine the products of the reaction of sulphuric acid with magnesium oxide, identify the salt formed and balance the equation. At the end of their discussion, they put up on the board the equation $H_2SO_4 + MgO = MgSO_4 + H_2O$. The group comprised one female (Lg1) and three male learners (Lb1, Lb2 and Lb3). This is only part of the discussion to illustrate how they drew on their different home languages (Table 12.5).

The excerpt begins with the group discussion the procedure to follow in resolving the problem. The learners debated which of the tasks to start with; determine the products first to identify the salt or construct and balance the

Table 12.5 Group 1 discussion in isiZulu and seSotho.

113	Lg1	*Nanku bhekani bhekani ukuthi nje kufanele* ***sibhalanse i-equation*** *ngendlela esijayele* ***ukubhalansa*** *ngayo* ***i-equation*** *and then ke sesizo* ***fomuleyitha*** *i-gama laleyo* ***salt and because of ama results*** *esowathola out of* ***i-equation*** *niya* ***andastenda?*** (here here look this is it *(pointing to an equation in her book)* it's just that we have to balance the equation in the way we always do and then we can formulate the name of the salt from the results we get out of the equation, do you understand?)
114	Lb2	*Phinda futhi* (say that again)
115	Lg1	*Sibhalansa i-equation masiqeda ukubhalansa i-equation i-end result esizoyithola sizo neyima i salt leyo because out of i-equation let's say we get sodium* (We balance the equation and then after balancing the equation the end result that we get we name the salt based on that equation let's say we get sodium…)
116	Lb3	*Lamoutlwisisa?* (do you understand her?)
117	Lb1	*Ushukuthi njengoba iso soqala sibhalanse le-equation?* (do you mean that since it is like this we first need to balance this equation?)
118	Lg1	*Hhmm masiqeda lentole le answer le siyitholile sineyima isalt* (yes and thereafter from the answer that we get we name the salt)
119	Lb2	*Sibhalansa yona kuqala?* (so we balance this one first?)
120	Lg1	*Kuzoba yigama let's say kuzoba yi nitric…* (it is going to be the name of the salt let's say it is nitric)
121	Lb1	*Oh sibhalansa le kuqala?* (so we balance this one first?)
122	Lg1	*Ja* (yes)
123	Lb3	*Kanti a reetsi reaction pele? Keona reyi balanse?* (but don't we need to do the reaction first? And then balance it?)
126	Lg1	*Maubhalansile sesibhalansile sesizoneyima …* (we'll name it after balancing)
125	Lb3	Ja e ya-*naming* I do understand mara you know what I'm saying? *mara ha riyibhalansa retswantsi rebhalanse* reaction this side *pele* (I do understand the naming but what I'm saying is that we need to balance the reaction this side first)

equation first and then name the salt. Lg1 argues that they should start by balancing the equation "...in the way we always do and then we can formulate the name of the salt from the results we get out of the equation." A lengthy exchange ensues with all four learners debating Lg1's suggestion until they reach consensus by turn 122, all in their home languages. The group went on to construct the correct equation and balance it, after which they successfully named the salt.

We believe that using their home languages made it easier for these learners to engage both procedurally, going beyond the routine process of the mathematical manipulation of the chemical equation and conceptually in joint meaning making. They challenged and pushed each other to explain and defend their thinking. They were able to support their arguments without being distracted by the language shifts, moving effortlessly between transliteration and code switching.

12.8 Discussion and Conclusions

Research on chemistry education has established that because of its complexity, chemistry is a difficult subject to teach and to learn. Over four decades ago Johnstone[42] proposed a model that recognises three domains of chemical knowledge; the macroscopic, the sub-microscopic and the symbolic to guide the teaching of chemistry. Johnstone argued that some of the difficulties in learning chemistry involved what he termed multilevel thought.[43] Thus, chemistry learning is about understanding abstract theoretical explanations of chemical phenomena and chemistry teaching must take into consideration this need for learners to think and understand the multiple domains of chemistry all at once.

The need to teach chemistry in ways that mediate learning amid this complexity imposes huge demands not only on teacher subject matter knowledge but also the use of appropriate pedagogical approaches. The implications for teacher preparation and resourcing of chemistry education cannot be over emphasised. However, in low socio-economic environments, investment in education is very low including teacher education.

In this chapter we have demonstrated the potential for argumentation as a teaching strategy and a learning tool in these low socio-economic contexts in South Africa. The vignettes illustrate possible pedagogical approaches that can be adopted to maximise the learning of chemistry in difficult contexts. With adequate preparation and support teachers can and do adapt argumentation strategies to facilitate the learner multiple thinking required to understand chemistry. We concur with Aydeniz and Gurcay's[44] argument to develop in teachers "epistemic and pedagogical knowledge of argumentation" and that the science teacher educators must "provide epistemic and professional development experiences to future science teachers so that they can help their students appropriate the epistemic and social norms of science in the context of argumentation" (p. 270).

Sound teacher epistemic and pedagogical knowledge of argumentation has potential to shift interactions in science classrooms towards a more dialogic discourse that creates opportunities for learner involvement and meaningful engagement with both the teacher and their peers.

However, in many low-income countries the challenges of teaching and learning chemistry are compounded by the teaching and learning of chemistry in a language that the learner is not proficient in. Thus, science teacher education has the added responsibility to model for future teachers strategies to mobilise and maximise all the language resources of the classroom.

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Appendix G: A manuscript ready to be published by AJRMSTE

Exploring teacher pedagogical practices that help learners make connections during the teaching of the Electrolytic cell at senior secondary

Mudadigwa Brighton and Msimanga Audrey

Abstract

Evidence from literature supports the idea that a hierarchical and coherently organised curriculum fosters meaningful learning. We argue that the learning can only be realised if teaching compliments the curricular coherence by making the connections explicit for learners. In this paper we report our observations on the extent to which selected teachers' pedagogical practices support this coherence in their teaching of the electrolytic cell. Five teachers were observed teaching the electrolytic cell and its underlying concepts at senior secondary level. The classroom discussions were transcribed and analysed using the Pedagogical link-making tool by Scott, Aguair and Mortimer (2011). The tool has three aspects; Pedagogical link-making for continuity, Pedagogical link-making for knowledge building and Pedagogical link-making for emotional engagement. In this case Pedagogical link-making to promote continuity was used to analyse the data to establish coherence and progression in concept coverage. According to Scott and colleagues an important part of teaching science is showing the learners how to make links between concepts within the lesson, across lessons and across grades. This is link-making for continuity. The data analysed for this paper was mainly from observations of five teachers teaching the topic Reactions in aqueous solutions. The teachers were interviewed after teaching in order to clarify some of the pedagogical practices observed during the lesson. There was no evidence of teachers helping learners to make the connections between concepts and thus make sense of the content themselves. When learners are not involved in link-making during the teaching and learning process, conceptual understanding of the topic is compromised. We discuss the implications of these findings for teaching and learning as well as for teacher education.

Continuity, Meaningful learning, Conceptual understanding, coherence, progression

Introduction

One of the aims of South Africa's Department of Basic Education (DBE) is to improve learner performance in the Physical Sciences, one of the subjects in which most learners continue to be perform poorly. This is also entrenched in the science Curriculum and Assessment Policy Statement (CAPS) in 2011 (Department of Education, 2011). The curriculum encourages the teaching of science for conceptual understanding and discourages strategies that promote reliance on memorisation which tend to lead to rote learning. However, learner performance and achievement in the Physical Sciences remains low. The DBE laments learner lack of understanding of basic concepts and failure to make conceptual interpretation. In fact, in a diagnostic report following the first CAPS examination in 2014, the DBE reported that learners struggled with questions that required scientific explanations, especially in the topic Chemical Change (Department of Education, 2014).

The problem of lack of conceptual understanding in Chemical Change topics has also been highlighted at university level (Potgieter & Davidowitz, 2010). The performance of first-year students was found to be poor in basic concepts such as Atoms and Ions, Mole Concept, Chemical Reactions, Acids and Bases Chemical Solutions and Stoichiometry. Elsewhere, in the world, Chemical Change and some of its subtopics have also been found to be a challenge for learners (Doymus, Karacop, & Simsek, 2010; Potgieter & Davidowitz, 2010). These all point to learner inability to make connections between concepts which is necessary for conceptual understanding.

For many decades link-making has been a topical issue in educational research with respect to teaching science for conceptual understanding. Research emphasises meaningful engagement in the classroom as a driver for learner understanding of scientific concepts. However, for this goal to be achievable, the learning material should be structured in a way that makes explicit the inter-relatedness of concepts. Equally, the teaching strategies employed by teachers should augment the meaning-making processes in the classroom. Furthermore, teaching and learning material that is anchored and builds on pre-existing knowledge has been found to enhance meaningful learning (Ausubel, 2012). Scott, Mortimer, and Ametller (2011) describe the ideas above, as Pedagogical Link-Making (PLM), which is a process they believe is fundamental to the teaching and learning of scientific knowledge. PLM is defined as a teaching and learning process where teachers and learners inter-link concepts in a constant meaning-making progression during classroom interactions.

Literature review

According to Ausubel (2012), meaningful learning is the ability of a learner to relate non-arbitrary and non-verbatim incoming knowledge to already pre-existing knowledge. The learning material should trigger possible links between the newer and the pre-existing knowledge (non-arbitrary) in the learners' cognitive structures. Novak (2010) suggests that meaningful learning is the facilitation of a construction of valid meanings and reconstruction of misconceptions (invalid meanings) in learners' cognitive structures. This definition does not only refer to links between prior knowledge and incoming knowledge as a relationship but further adds to the construction or building of conceptual understanding. The term conceptual understanding itself refers to the internalisation of the inter-linked concepts within the mental structure of the learner (Konicek-Moran & Keeley, 2015). Hence the way in which thoughts are organised and structured has a significant impact on the internalisation of ideas by learners.

The quality of meaningful learning depends upon the organisational structure of the learning material and its conceptual richness. This organisational quality of the learning content is for us what is referred to as link-making. The DBE uses the word coherence for the same concept and suggests that the learning material should be organised in such a manner that it is coherent and logical to facilitate learner comprehension (Department of Education, 2011). However, even when the content is clearly organised, it is the responsibility of learners to construct meaning on their own (Nicol, 2009). Novak (2010) argues that the learners must deliberately and purposefully choose to relate novel information to what they already know. In their study of the sequencing of essential chemistry topics, Sibanda and Hobden (2016) found that Physical Science teachers' preferred concept arrangements that were not consistent with the prescribed new CAPS. Generally, they found that 70% of teachers sequenced topics from microscopic-level to macroscopic-level, whereas the opposite was true with the new curriculum. This difference suggests a disjuncture between policy and practice and casts doubts on whether and how teachers would be able to promote continuity considering the prescriptive nature of the CAPS work schedule in terms of sequencing of concepts.

One cannot dispute the power of memorisation in getting learners to just pass examinations, many already do. Prosser and Trigwell (1999, p. 99) identify deep memorisation as the method used by learners in revising for examinations. In meaningful memorisation learners repeat the text to be learned several times in a manner that deepens understanding focussing on different aspects with each repetition. However, the knowledge acquired through memorisation will soon be forgotten, as it is irretrievable from long-term memory. Novak (2002) argues that even if it is retrieved learners can scarcely apply it to solve problems in new contexts. Therefore, memorisation only caters for the immediate outcomes rather than for sustainable acquisition of content knowledge. In their study of constraints on the development of first-year university learners' mental models of chemical phenomena Chittleborough, Treagust, and Mocerino (2002) found that even at university level students do use memorisation. Students confessed that most concepts were rote learned and that they could not remember much even if they had passed the examinations, thus confirming the argument that memorisation of concepts did not result in-depth understanding and storage in long-term memory. Consequently, learners fail to integrate their existing knowledge with new knowledge (King, 2009). Meaningful learning, however, empowers learners with conceptual understanding and enables transfer to other contexts as often required in tertiary education. Hence, pedagogical link-making by Scott et al. (2011) is fundamental to the teaching of science for conceptual understanding. We now discuss how we used Pedagogical link making as an analytic tool in this study.

Analytical Framework

Pedagogical link-making, (PLM) consists of three primary forms. Firstly, pedagogical link-making to support knowledge building: constructing significant relations between different types of knowledge for learners to acquire a comprehensive understanding of the content knowledge. Secondly, pedagogical link-making to promote continuity: involves making connections between concepts that have been taught over different time scales; and thirdly, pedagogical link-making to encourage emotional engagement: the teacher's ability to create links during the teaching and learning process to boost a constructive emotional response from learners. This paper draws on the second form, pedagogical link-making to promote continuity, to understand how teaching can become "the development of a scientific story" (Scott et al., 2011, p. 13); teaching that helps learning go beyond memorisation. We seek to answer the research question, to what extent do chemistry teachers demonstrate for learners the connections between concepts in the teaching of the electrolytic cells at senior secondary level within the lesson and across lessons and grade levels.

Link-making to promote continuity involves making connections between concepts that have been taught over different time scales. Scott et al. (2011) identified two approaches to promote continuity: link making to develop the scientific story and link making to manage or organise time. The curriculum is generally covered over a period of time and for the South African senior secondary level this happens over three years (Grades 10 to 12). During teaching and learning, concepts must be linked to other related concepts in the lesson; to those that have been covered in the past and to those that are still to be covered in future. Scott and colleagues refer to this as developing and maintaining the scientific story of an idea by making links between interrelated concepts. In this study we view teaching to promote continuity as encompassing the arrangement of interlinked concepts hierarchically and coherently. However, it is not only the teacher's responsibility to make links between concepts. While the teacher should purposefully and explicitly show the connections s/he must also provide opportunities for learners to engage on a social plane and make the connections for themselves. To analyse the data for presentation in this paper we used the second approach PLM to promote continuity, that is, developing the scientific story.

Link making to develop the scientific story

Mortimer and Scott (2003, p. 3) define development of the scientific story as "providing a commentary on the unfolding scientific story, to help learners follow its development and to see how it fits into the wider science curriculum." The development of a scientific story is attributed to the ability of the teacher to link concepts in current lessons with previous and subsequent lessons using learners' previous knowledge. Scott et al. (2011) argue that links can be made during the lesson through recap and elicitations. Table 1 below explains the three levels of link-making for the development of a scientific story that promotes continuity.

Table 1: Different scales of link-making to develop a scientific story

Links to develop a scientific story	Explanation
Macro-scale	Extended time scale separated by months and years.
Meso-scale	Intermediate time scale separated by days and weeks.
Micro-scale	Immediate time scale separated by minutes or within the lesson.

Link-making at the macro scale entails continuity links made on the extended time scale (months and years) involving teaching across different sections of the science curriculum. For instance, for the South African science curriculum it would involve linking concepts taught at all three senior secondary Grades 10, 11 and 12. The meso scale requires continuity links made on an intermediate time scale (days and weeks) involving referencing of concepts between lessons or topics. This would be linking of concepts taught within the same grade, for instance. The micro scale refers to continuity links made on the immediate time scale (minutes within a lesson), involving referencing of concepts/events within a lesson.

Methods

A qualitative case study methodology was adopted, working with two volunteer science teachers, teaching at different schools. The teachers were observed teaching the topics Reactions in aqueous solutions (Grade 10), under the general topic Chemical Change. The two participants had a professional teaching degree and an undergraduate degree in chemistry. Data was collected through both audio and video recording. An audio recorder was strapped to the teacher to capture all the proceedings of his teaching. Video recordings of the entire class were also done to capture the extent of learner participation and any non-verbal communication. After the lesson observations, the two teachers were interviewed to establish reasons for the observed teaching sequences. Each teacher was assigned a pseudonym.

The transcribed lessons and interviews were analysed using the scales of continuity as described by Scott et al. (2011). For member checking the participating teachers were asked to comment on emerging trends from the analysis. Also, two colleagues who understood PLM were requested to compile the scales of continuity on the lesson transcripts. Consensus was reached through several cycles of discussion and analysis until the results were consistent in all the different analyses.

For this article, only the first lesson of each participant was analysed using pedagogical link-making to support continuity at Grade 10. The first lesson can be viewed as a corridor that connects significant learning areas. From it teaching can branch into different pertinent individual concepts. Grade 10 is the first level at which the topic, Chemical change is taught and insights on how link making happens when the topic is introduced can inform understanding of how teachers begin to help learners make connections with what is still to be taught at Grade 11 and 12.

Analysis of results

Each Grade 10 teacher's first lesson was transcribed and analysed using the Scott et al. (2011) framework as described above. Figure 1 below shows the number of links made by each of the two teachers at the different levels of link-making; that is, at the micro-, meso- and macro scales. In the figure, PC1 represents the first approach of pedagogical link making for continuity and the chronological numbering 1, 2 and 3 represents the three scales at which link making is made. Thus, PC1-1 means pedagogical link making for continuity in developing the scientific story with a focus on link making at the micro scale; PC1-2 is link making at the meso scale while PC1-3 is at the macro scale.

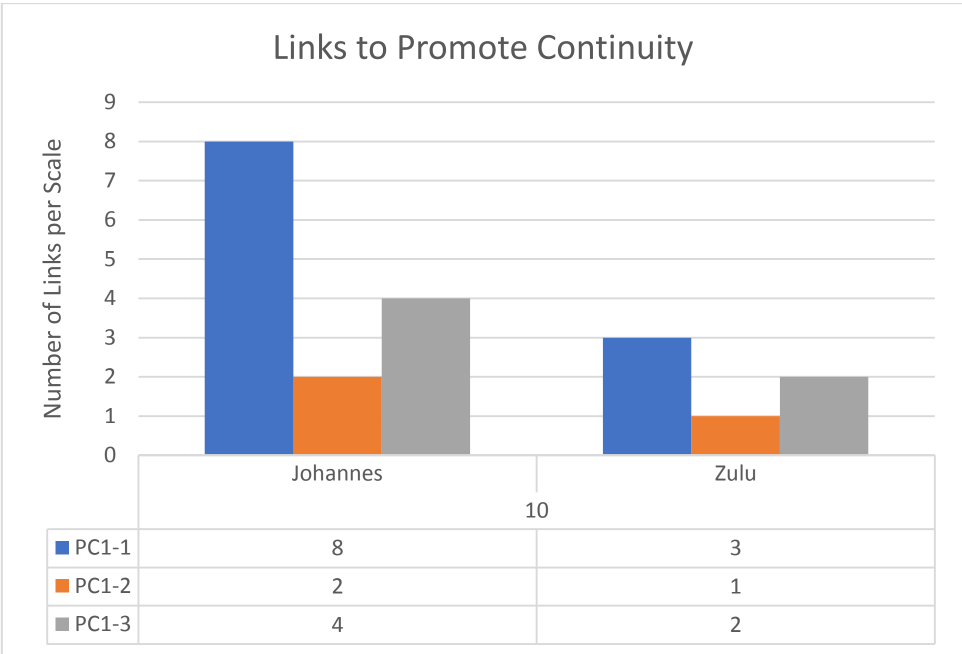

Figure 0.1: Number of links made by each Grade 10 teacher during the first lesson

The micro scale had a total score of 11 links between the two teachers, which was the highest compared to the meso scale (3 links) and the macro scale (6 links). In the first lesson macro scale links were used to connect the concept of Reactions in aqueous solutions (A Grade 10 topic) with other concepts in previous topics separated by months, particularly Chemical bonding. Both teachers made the least meso scale links than the other two levels of link-making. It would be expected that the micro-scale would have the highest score as it involves linking concepts in the current lesson. Here learners and teachers continually referred to the concepts being discussed at the time. The graph above shows that in total Mr Johannes made more links than Mr Zulu in total. Mr Johannes seemed to successfully engage learners in making the necessary links between scientific ideas within the lesson because of the social constructivist approach he adopted. Through the teacher-learner and learner-learner engagement prevalent in Mr Johannes' lesson, he and his learners could make more links within the lesson.

Another striking finding relates to patterns of both teacher and learner link making practices as shown in Figure 2 below.

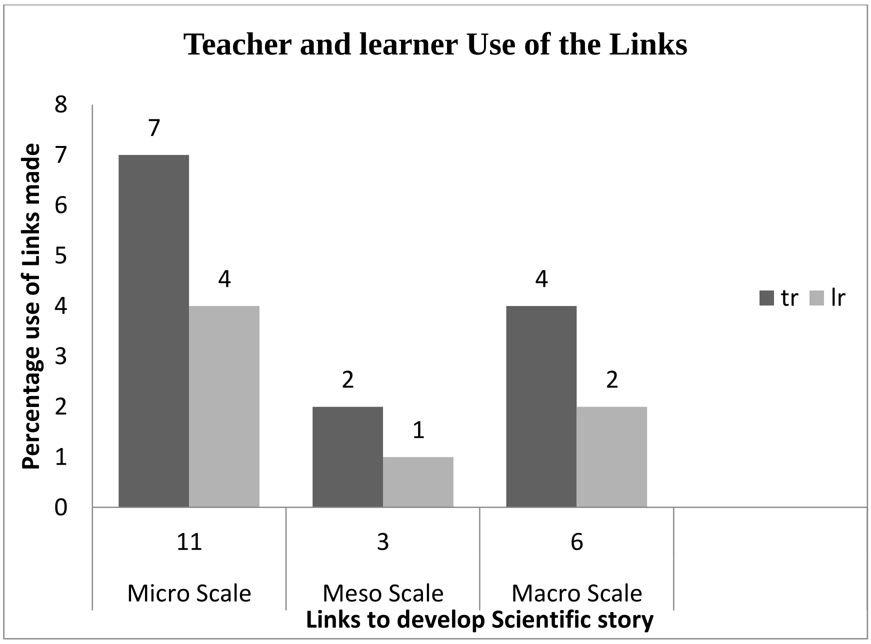

Figure 0.2: Comparison of Grade 10 teachers (tr) and learners (lr) use of the macro, meso and micro links

From Figure 2, it is clear that most of the links were made by teachers across all scales of linking-making to promote continuity. Teachers made 4 links out of 6 links at the macro scale, 2 out 3 links at the meso scale, and 7 out of 11 links at the micro scale. Learners were more involved at the micro level with 4 out of 11 links between the two classes. Both teachers allowed learners to discuss either in whole class discussions or in small groups. Small group discussions were observed in Mr Johannes' class. Scott et al. (2011) Research suggest that both teachers and learners must make links and the role of the teachers is to indicate the relationships and help learners to make those connections. While it is commendable that learners made connections in the micro scale link-making this is not enough for the development of a complete scientific story.

Case by Case Analysis of link-making

The graph below shows the number of links in each teacher's lesson.

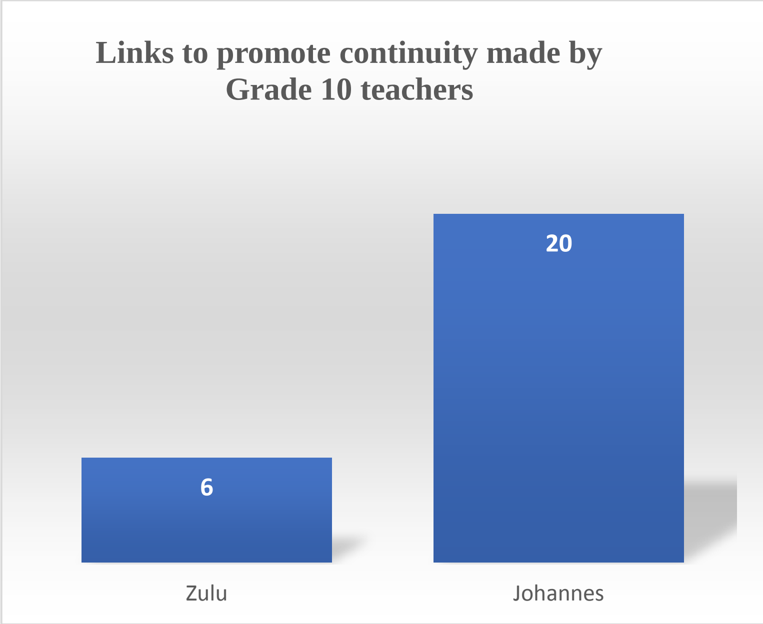

Figure 3: Number of links made by each teacher in the lesson

Mr Johannes made a total of 20 link-makings which was three times more than what Mr Zulu made in his lesson. Evidently, Mr Johannes did fulfil the requirements of teaching for conceptual understanding by making more links during his lesson presentation compared to Mr Zulu. There is a need to analyse the depth of the teacher links to ascertain how relevant the link-making was in teaching for conceptual understanding. In the next section, we illustrate the link-making practices from the lesson observations for both teachers.

Mr Zulu's first lesson was on the concept of precipitation. His previous lesson had been on electrolytes, and he started the new lesson by recapping on that concept. The conversation is captured in the excerpt below.

Turn	*Speaker*	*Transcription*
1	*Zulu*	*.... Back to our work now last time we were talking about electrolytes is that correct?*
2	*Class*	*Yes*
3	*Zulu*	*(interruption by latecomers)* *We said they were substances which dissociate in water to form ions is that so? And I gave you homework ... that is sodium chloride, potassium bromide, and potassium permanganate. Then I said to show the dissociation of this into their ions.* *Who did the homework? Somebody to do it for us. How does it dissociate into its ions?* *(Teacher moving around checking learner's work)*
4	*Zulu*	*Right Sessi can you go and do it on the board what you did there.* *(Learner goes to the board and writes the equation of dissociation quietly; she wrote the following equation)* $NaCl_{(s)} \rightarrow Na^{+}_{(aq)} + Cl^{-}_{(aq)}$
5	*Zulu*	*Right, when sodium chloride dissociates in water it will form positive sodium ion and a negative chloride ion. Correct?*
6	*Class*	*Yes*

7 Zulu And we did this when we were looking at bonding in term 1, where the transfer of electrons is from the sodium atom to the chlorine atom. Now because of time, I'm going to give you the memo for the other 2 is that so.

In turn 1 the teacher is pointing out that they discussed electrolytes in the previous lesson (meso scale), which Sessi is seeing to remember and she successfully summarises it in the form of an equation on the board. The story of ions in aqueous solution is a foundation for the future concepts of precipitation where ions react to form a solid in aqueous solution. The teacher identifies the link which the learner is also able to make. The story, therefore, unfolds without a problem.

In turn 4 the teacher then makes a macro scale link, where he refers to chemical bonding done in term 1 of the same grade. The lesson described here was observed in term 3. It would have been interesting to observe learners making the connections on the concept of chemical bonding if the teacher had given them the opportunity. This would demonstrate how learners connect the lesson at hand with what was done approximately six months ago. Unfortunately, it was the teacher who made the link and then went on to explain without engaging learners. Mr Zulu terminated the dialogue on chemical bonding and revision of homework because of time.

Thus other learners did not have an opportunity to demonstrate their ability to make the connections on the concepts of electrolytes because of time. We constructed a concept map of our understanding of how the story developed in Mr Zulu's lesson as shown in Figure 4 below.

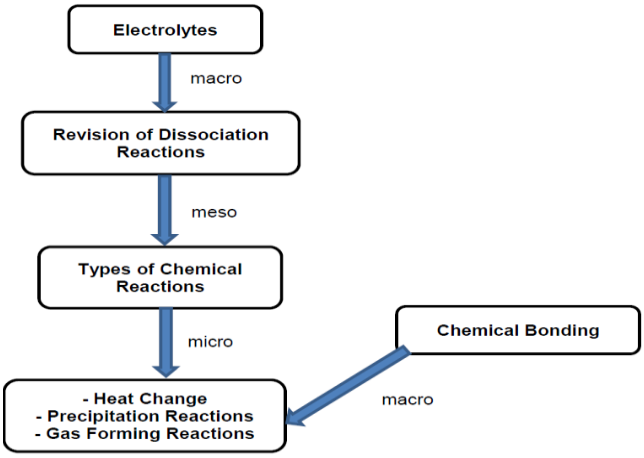

Figure 4: Deduced conceptual structure and link-making in Mr Zulu's lesson

The topics referred to in the class discussion were relevant, but the question remains, did Mr Zulu exhaust all necessary concepts that would have enhanced learner understanding of redox reaction, acids and bases?

Now Let us consider Mr Johannes's lesson. Mr Johannes was teaching the same topic at a different school. The next below shows how Mr Johannes introduced his lesson.

Turn Speaker Transcription

1	*Johannes*	*When I introduced this topic to you yesterday, I said when we look at Chemical Reactions, there are two types of chemical reactions; Ion Exchange and Redox Reactions is that so?*
2	*Class*	*Yes*
3	*Johannes*	*From there, looking at the redox reaction there are 3 types, we have got precipitation reaction, gas forming reaction and acid-base reactions. We are going to start with the precipitation reaction, are we together?*
4	*Class*	*Yes*
5	*Johannes*	*Before I get into more detail, we also looked at the dissolution of salts, when we were adding salt into what?*
6	*Kenny*	*To water*
7	*Johannes*	*To water. When we added salt to water, we found out that, what do they do?*
8	*Siya*	*They dissolved*
9	*Johannes*	*Some dissolved right?*
10	*Class*	*Yes*
11	*Johannes*	*When they dissolved, they form what?*
12	*Kenny*	*They form a solution*
13	*Johannes*	*They form a solution, right?*
14	*Class*	*Yes*
		.....
16	*Class*	*Yes*
17	*Johannes*	*When you look at the water cycle, we have water falling as what?*
18	*Mattie*	*Solid*
19	*Getty*	*Snow*
20	*Johannes*	*They fall as what?*
21	*Class*	*Snow*
22	*Johannes*	*As snow right*
23	*Class*	*Yes*
24	*Johannes*	*Very correct besides snow, they can fall as what?*
25	*Class*	*As rain*
26	*Nolly*	*As hail*
27	*Johannes*	*As rain right. So when we talk about precipitation is something that is coming from somewhere, now from the water cycle, it is water falling from the sky. But when we are looking from a chemical reaction, precipitation is the falling of a solid out of a solution. The falling of a solid out of a what?*
28	*Class*	*Solution*

In the extract above, line, one Mr Johannes made a meso scale link with the previous lesson. The concepts that were linked are ion exchange and redox reactions. In line 5, The teacher made a meso scale link again when he referred to the dissolution of salts, where the concept had to do with releasing of ions into solution. The teacher engaged with the whole class and with individuals to access their understanding of the previous lesson. The water cycle is a discipline-based link (macro scale) between Grade 9 Geography content and Chemical Change in Grade 10 and shows conceptual progressions from one grade to another. The connection between precipitation reactions and heterogeneous mixtures was also linked to Matter and Material that was covered in the first term. The diagrammatic conceptual outline as interpreted by the researcher from lesson structure is shown in Figure 5 below.

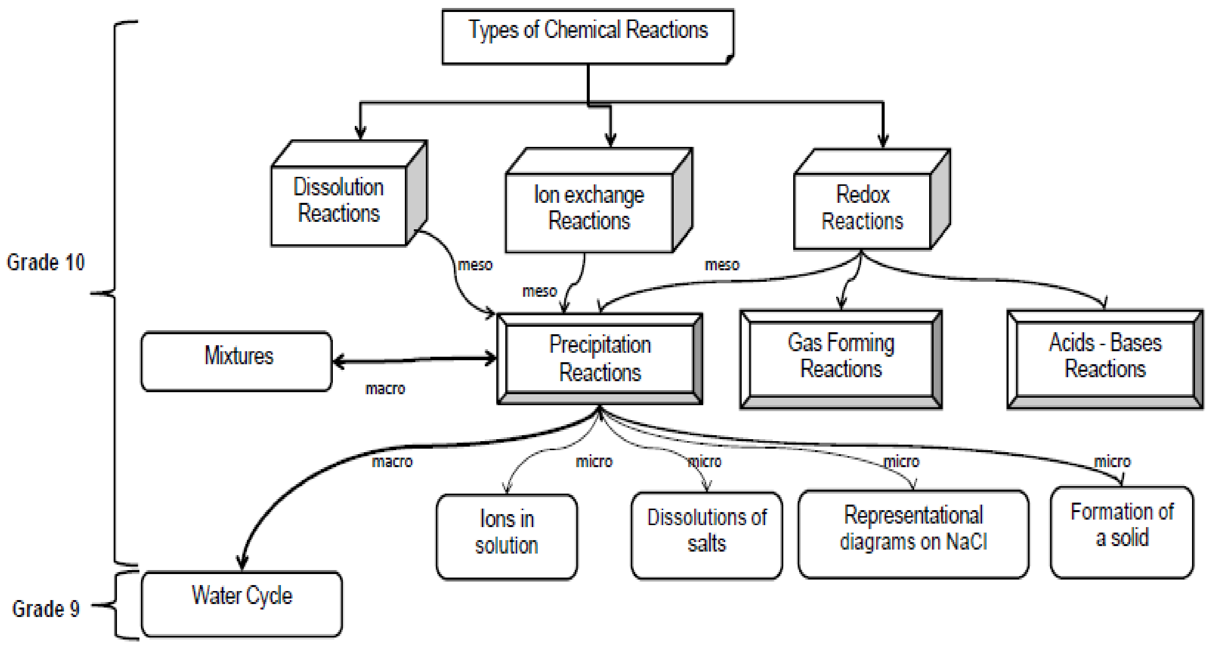

Figure 5: Deduced conceptual structure and links from Mr Johannes's lesson

The concept flow diagram is not linear, but it's a web of interrelated concepts. The way the teacher ordered his scientific ideas was systematic and showed competence in linking concepts coherently. Although learners were engaged, they were not given an opportunity to explain their contributions to ascertain their understanding. Nevertheless, in groups learners fully involved with each other. The excerpt below shows the discussion of one of the groups on the formation of silver chloride from silver nitrate and sodium chloride using submicroscopic representation diagrams on a worksheet.

Turn	*Speaker*	*Transcription*
70	*3rd*	*I think it's going to be solid*
71	*1st*	*Yeah*
72	*3rd*	*But how is doing it*
73	*1st*	*He said we should draw a diagram to show how to represent silver chloride*
73	*2nd*	*How, in our notes?*
74	*1st*	*Yeah*
75	*4th*	*So silver nitrate it's going to continue, and it's going to be solid*
76	*3rd*	*yeah it might be solid*
77	*2nd*	*We can't just say solid*
78	*4th*	*We need to find the solution first*
79	*2nd*	*Yeah*
80	*1st*	*Isn't it going be*
81	*4th*	*Isn't it going to be what*
82	*1st*	*I am sure the ions exchange here*
83	*3rd & 2nd*	*Yeah*
84	*2nd*	*So this…*
85	*1st*	*It will be silver chloride*

The first 1st learner was leading the argument and she was able to link ion exchange (meso scale) with precipitation reactions and she correctly identified that silver chloride would be formed. In this excerpt, there is evidence that the 1st learner understood the concept of ion exchange and was able to solve the precipitation problem, in the process helping her fellow learners. In this lesson the teacher talk was 8 minutes, teacher-pupil interaction was 7 minutes, and group discussion was 13 minutes. Mr Johannes's lesson can now be compared to Mr Zulu's lesson.

Cross-case analysis

The two teachers were knowledgeable on the subject matter of precipitation because of the way they linked the underlying concepts of precipitation such as dissolution and solubility. Both teachers made the links themselves and did not allow learners to make the links during the introductory part of the lesson. Their argument was that learners should be presented with underlying scientific concepts as guidance for further discussions.

The first difference was the absence of group work in Mr Zulu's lesson. He spent 13 minutes of the lesson on teacher talk, 9 minutes on teacher-pupil interaction. Basically, his approach was teacher centred compared to Mr Johannes's method which was learner-centred as he involved learners in his discussion.

The second difference was in the number of concepts linked and the way they were connected. For Mr Zulu's lesson, the concept interrelatedness structure was linear whereas Mr Johannes's exhibited a network of linked concept with several branches. This shows the difference in teaching approaches between Mr Johannes and Mr Zulu. There is not much evidence of about learner understanding in Mr Zulu's class except that for Sessi who correctly did the dissolution homework exercise on the board. Other than that, the learners did not participate except for providing answers as a class whereas in Mr Johannes's class learners did participate, though teacher-pupil interactions consisted of one-word answers. Nevertheless, in groups, learner-learner interactions were rich with discussions though in several cases teacher was called to arbitrate on some disagreements.

During the interviews when teachers were asked about learner engagement in making links with the previous knowledge. Both teachers complained about time, see excerpts below from interviews with the teachers.

Researcher	*How can we actually teach the curriculum without being in a rush? What is the problem, why are we rushing?*
Johannes	*Okay, when I… look at the schedule fine, it has coverage, but I don't… I usually comment… my schedule doesn't cater to all my needs it's not fair to everyone. Yes, for the fast learners but for the least, slowest learners it doesn't cater for them even though I have morning lessons… Under normal circumstance, if there is positive contact time my learners should understand but now, I try to put extra lesson whether morning or afternoon but still my least learners they are not catered for with my schedule… I think… I've always commented on there that it doesn't cater for all my learners, worse the slowest learners.*

Mr Zulu had this to say;

Zulu	*….. I mean if we are, to be honest, some of these things we are doing it in a rush because of the time factor. We are doing it in a rush we just*

want to squeeze them and blah blah then we move and go on to Grade 11. We think that is our thinking now that we should have grasped these things in grade 10, and then we move on. But if we polish it at Grade 10, I don't think that we will be having this problem. ….

The two teachers indicated that time was the most significant factor in not engaging learners because the syllabus was too congested. In my first visit to Mr Zalechi, his first lesson which was supposed to be 40 minutes was 22 minutes long. This is because it was an assembly day which lasted longer than what was indicated on the time-table. Also learners took long to come into the classroom. The fact that learners trickled into classes late was observed in all the five schools though this was worse in these two schools reported here. Hence, most lessons we observed were shorter than the time allocated on the timetable. Therefore, time is a twofold factor; firstly, the prescribed time is not fully utilised due to late coming and disturbance in the school routine, and that the syllabus is too congested.

Discussion

In the quest for teaching for conceptual understanding, the learners' previous knowledge is important as it informs the teacher about pre-conceptions of the learners. Ausubel (2012) argues that new knowledge triggers conceivable links within the learner's cognitive structure that relates to the already existing concepts. In the case of Mr Zulu, there is little evidence that learners successfully linked previous knowledge with the concept of precipitations. There was no input from the learners during the discussions to ascertain the depth of their comprehension. Contrary to Mr Zulu's approach, Mr Johannes provided opportunities for learners to construct their own understanding through small group discussions. Learners were able to make links between interrelated concepts successfully. Novak (2010) argues that the focus of good instruction is to enable learners to take responsibility for their own meaning-making, not for the teacher to do everything for them.

Bimbola and Daniel (2010) state that unorganised and incoherent learning material compounds the problem of the chemistry subject and forces learners to learn by memorisation only and regurgitate the isolated concepts. By not connecting or showing the relationship of paramount concepts in a topic, learners find it difficult to integrate their existing knowledge with new knowledge and are forced to memorise to pass examinations (Sirhan, 2007).

Contrary to Mr Zulu's linear link-making, Mr Johannes was able to link several concepts with the topic of precipitation reactions to form a web of conceptual links. A network or net of concepts exhibits the richness in the connectedness of the scientific ideas that enhance meaning-making. This logistical arrangement of the learning material and its conceptual richness drives the quality of meaningful learning (Novak, 2010). The linear outline is limited in the scope of the relationship of a concept with other scientific concepts, thereby encouraging learning of isolated facts which is tantamount to rote learning.

If learning by regurgitating happens this early at Grade 10, by the time learners get to Grade 12, when they have to write an examination that demands an in-depth understanding of a hierarchical and coherent curriculum, this will not remember the underlying concepts. They will not manage the demands of the subject because they have not been interlinking topics in lower grades. Hence, in the exit grade learners find the subject problematic to comprehend and resort to memorisation and teachers resort to the drill. When these learners proceed to university, they cannot remember most of the concepts, as shown by the findings of Potgieter and Davidowitz (2010).

In order to provide opportunities for the conceptualisation of content knowledge by both teachers and learners, the syllabus needs streamlining. The reorganisation of the Physical Science curriculum may not mean removing some concepts but rather separating it into its individual components of Chemistry and Physics from Grade 10. The principal argument is that the Physical Science curriculum covers a vast range of topics and the content calls for high levels of conceptual understanding. In their effort to of complete the syllabus, teachers are forced to rush through the content and resort to linear conceptual structures and very little link-making which creates conceptual gaps for learners. Consequently, teaching and learning focus on discrete pockets of knowledge which inevitably push learners towards rote learning to achieve their assessment goals. We recommend that teacher education and teacher professional development should include in their programmes deliberate opportunities for PLM teaching to empower science teachers and hence benefit learners.

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