PROBING LEARNERS' CONCEPTUAL UNDERSTANDING OF OXIDATION AND REDUCTION (REDOX) REACTIONS: A CASE STUDY

By

BILLEY BRIGHT ADDAM

A

thesis

submitted in partial fulfilment of the requirements for a

MASTERS DEGREE

in

EDUCATION

of

RHODES UNIVERSITY

JANUARY 2004

Dedication

This research is dedicated to Ms. Ellen Tupra and to the memory of Mem Akresi.
Two mothers who made me what I am.

ABSTRACT

The new political dispensation in South Africa has seen a lot of changes taking place. The democratic wind, which has been blowing in all spheres of the political arena, could not leave out Education. This has led to the transformation in education and the revision of the curriculum guided by the Outcomes-Based Education philosophy (OBE). Thus, require education authorities as well as educators to look at education more comprehensively.

The challenge posed to educators now is to develop tools and strategies that will make learning accessible to as many learners as possible and to teach for understanding and construction of knowledge.

The principal objective of this study was to investigate the important role the learner's prior knowledge plays and the use of different tools and strategies in stimulating conceptual understanding and construction of knowledge of redox reactions. This was done using learners' own investigations, practical activities, teaching settings and a workshop. The findings show that the learners lacked organized and structured prior knowledge. Learners could not integrate prior experience with new experience. The main issue seems to be the failure of learners to relate classroom experience to everyday redox phenomena. Possible reasons are discussed with some implications for teaching redox.

The study further postulates that to assist learners to develop conceptual understanding of redox reactions, different tools and strategies should be employed and teaching made relevant to real-life situations. In so doing, redox concepts would not be abstract to learners.

TABLE OF CONTENTS

CHAPTER THREE:RESEARCH PROCESS AND METHODOLOGY

CHAPTER FOUR: DATA ANALYSIS AND FINDINGS

List of Tables

ACKNOWLEDGEMENTS

My profound thanks to my supervisors Mr. Ken Mlungisi Ngcoza and Mrs. Gill Boltt who propelled this project out of the realm of mere idea and for their dispensable help in turning my ideas into a good reading report; Sean Harper who was enthusiastic about the report write up and corrections; Noreen Burton, Fiona Crawford and Judy Cornwell for their perceptive copy editing, Asafo-Adjei T. for accommodating me throughout the research period; my learners with whom I had indescribable pleasure of working and battling through this research project

.

I am appreciative of the individual and collective support of the staff of the Department of Education (Rhodes University, East London and Grahamstown).

Further, in undertaking this academic venture, I benefited immensely from the invaluable financial assistance from CARNEGIE

Lastly, to my friends and family especially **Ms Babalwa Sitshefuta** (my wife) and **Bill Hlomla Adam** (my son) for your loyalty, unflinching moral support and tolerance I say a big thanks.

CHAPTER 1

INTRODUCTION

> Research is like marriage; full of surprises and unpredictable. As it progresses so the exuberance diminishes. However, perseverance and persistence keeps it in shape till the final full stop is done. (Addam, B. 2003, personal reflections)

1.1 Introduction to the chapter

The way learners are introduced to oxidation and reduction in schools may not promote understanding of concepts. Definitions are sometimes in conflict with linguistic reasoning, and explanatory references to historical development and real-life situations are seldom given. In this study, the understanding of these concepts is the primary concern starting with the learners' perspective on the 'experts' point of view.

In this chapter, an overview of the research topic and a brief historical background is delineated. The research problem will be discussed and subsequently contextualized, arguing the relevance of eliciting learners' prior knowledge. Also focus is placed on the importance of relating real-life situations to classroom teaching and learning of science to enhance learners' conceptual development regarding science especially oxidation and reduction reactions (redox). The rationale for the research problem, the methodological preference and the research strategies are deliberated upon as well. The chapter ends with a general outline of the other chapters.

1.2 Background to the study

Learners' knowledge of science, especially oxidation and reduction (redox) reactions is often characterized by lack of coherence. Learners do not possess a well-founded basic framework regarding redox reactions in which newly acquired experience can be integrated. Redox reactions can be considered to be the most 'elementary' of all chemical processes because it is only by means of this reaction that elements can be changed chemically. Thus a conceptual understanding of redox reactions is inevitable as far as humankind is to appreciate that reactions such as the combustion of fuels (oil), the metabolism of fat in the body, photosynthesis in green plants, respiration in living organisms and the operation of batteries are essential.

1.3 Brief historical background

According to Blignaut, de Villiers, Finnemore, Gibbon, Hicks, Jordaan and Marias (1988, C1: 4), Lavoisier A. L. (1743 – 1794) a French chemist was the first person to introduce the term 'oxidation' after he realized that combustion involves the combination of a substance with oxygen. Before then, "phlogiston" (Greek: 'fire – stuff') theory was accepted by all scientists. This theory regarded heat as a type of "fire substance" which escapes from a substance on heating. Lavoisier's finding gave rise to the traditional concept and definition of oxidation as the addition of oxygen to a substance and the removal of oxygen as reduction. This concept of addition and removal of oxygen as redox persisted for many years and in the course of time it became clear that the two processes occur simultaneously. J. Liebig (1837 cited in Blignaut *et al.*, 1988, C1: 5) proposed another definition of 'redox'. He defined redox in terms of removal and addition of hydrogen.

With the appearance of the periodic classification of elements, it came to light that non-metals such as sulphur, chlorine and iodine behave similarly to oxygen (they can easily combine with substances). This serves as a limitation to the Lavoisier and Liebig definition of oxidation. G.A. Lewis (1916 in Blignaut *et al.*, *ibid* C1: 5) with his electronic theory of valence laid the ground for defining redox reactions as a reaction with the transfer of electrons. However, the terms 'oxidation' and 'reduction' are today connected to change in oxidation numbers indicating the quantity of electron(s) gained or lost, a term introduced by W. Latimer (cited in Blignaut *et al.*, 1988, C1: 5).

1.4 The research problem

Scientific knowledge in today's world is advancing at an extraordinary pace. In many schools today, science is studied only as a theoretical subject with intermittent demonstration of experiments. However, emphasis is now placed on conceptual development, understanding of concepts and the applications of the concepts in real-life situations. Newton (1988: 9), exhorts educators to utilize the experience of learners in helping them to apply what is learnt in life outside school. The traditional view about science as an abstract subject is giving way to the perception of scientific concepts as human constructions from real-life situations. The question that immediately comes to mind is: How could we teach science so that learners can develop conceptual understanding of scientific concepts? There is evidence to suggest (Rignes and Soudani, Cross, Sivade and Medimagh, 2000) that this conceptual understanding often does not exist or exists in a deficient form. Ringnes and Soudani *et al.* are some of the researchers who have researched the exact difficulties learners experience in developing this understanding.

In order to address the problem mentioned above, the following questions need to be explored. These questions are posed as heuristic components of the overall research questions, which will be formulated subsequently.

- What perceptions and experience do learners carry into new experience (redox reactions)?
- Does the old experience stimulate new experience?
- How do learners organise, structure and apply existing knowledge within the context of redox reactions?
- What role do learners' own investigations play in their conceptual development of redox concepts?
- Do practical activities contribute towards conceptual understanding of redox reactions?
- How do conversations, discussions, debates and workshop of findings from practical activities assist learners to understand redox phenomena?

These questions will be addressed theoretically and empirically. The main research question is:

- **How could prior knowledge elicitation and practical activities with a variety of teaching tools and strategies used in arguing findings contribute towards conceptual understanding of redox reactions?**

1.5 Aims of the research

The ultimate aim of the study is to scrutinise the effect of old experience on new experience, and also to examine the role played by various tools and strategies in enhancing learners' conceptual understanding of redox concepts.

1.6 Context of research

The topic of oxidation and reduction was selected as the subject context for investigation after my learners were surprised at a project given to them (paragraph 3 of page 4). Secondly, it forms an essential component of the science curriculum and the concepts are spread throughout all science disciplines. Blignaut *et al.* (1988:10) pointed out that oxidation and reduction (redox) reactions; an integral component of electrochemistry covers a wide variety of chemical processes, extending from photosynthesis and metabolism to the combustion of coal and oils and the recovery of metals across a broad spectrum of energy-producing reactions.

Some research has been conducted into learners' perceptions of redox reactions. Sisler and Van der Werf (1980) conducted studies to investigate and identify the nature of the difficulties that high school learners in America have in understanding redox concepts. Soudani, Sivade, Cros and Medimagh (2000), investigated the difficulties students have using these concepts in different situations and correctly using related terminologies to solve problems. A study by Garnett, Garnett and Treagust (1990) was directed towards learners' understanding of the concepts of redox reactions and their application of these concepts to solve related problems. Ringnes (1995) also reveals difficulties students have with the concepts of redox reactions. According to Soudani *et al.* (2000), many published articles about redox reactions are concerned with a summative assessment and not the conceptual understanding of the learner. This created a platform for redox reactions to be explored and approaches identified that will assist learners to develop conceptual understanding and its applications in real life situations. In my view, learners should be challenged to create their own primary experience of conceptual understanding, which will lead naturally to their secondary experience of construction and organization of knowledge.

Learners participating in this research were given this project before the investigation: to prepare a very simple voltaic cell. In doing this project, one of them twisted a spiral of a clean magnesium ribbon around a thick copper wire and connected the top ends to the terminals of a small lamp holder into which a 1.5V light bulb was screwed. He left the two ends free, as illustrated in Figure 1.1. He then placed the combination of the copper wire and magnesium ribbon into a drinking glass filled with a concentrated solution of copper (II) sulphate solution. He was surprised to see that after a few seconds, the bulb burnt lightly.

- Why the surprise?
- What has gone on?
- What learning has taken place?

These are some of the questions that need answers.

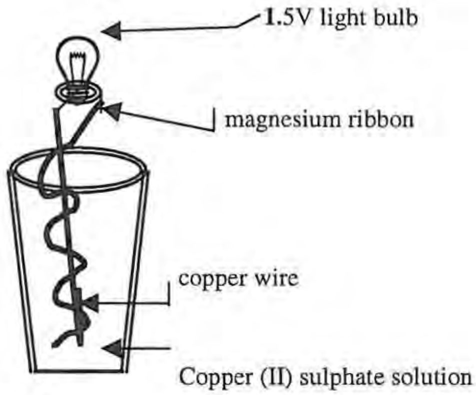


Figure 1.1

1.7 The research philosophy

Outcomes-Based Education (OBE) philosophy, which underpins C2005 and an accompanying pedagogy based on a constructivist theoretical framework, emphasizes the importance of learners' construction of knowledge *(ibid)*. Furthermore, OBE philosophy encourages educators to design and organise experiences or situations, taking into account the learners' environmental conditions that will affect the learner's ability to construct their own meaning and get an understanding of what they learn (Curriculum 2005). This is the principle underlying constructivism and this is the framework within which the research was conducted.

The study adapted an emancipatory approach (all the learners getting involved in almost all the teaching and learning program), which allowed the learners to strive to organise their experiences in terms of pre-existing mental structures or schemes (Bodner 1986: 873), which allows for the possibility that learners construct knowledge and meaning in different ways, depending on one's experience or mental structure. Interaction with my learners revealed that learners come into new experiences with perceptions, experience and knowledge, which are sometimes disorganised. This made the probing of learners' prior knowledge essential in creating the environment for the learners to explore and construct understanding and knowledge through the designed activities.

1.8 Approach to the research

The research design is exploratory and descriptive. Practical activities (including learners' own investigation), discussions, conversations, debates, teaching and learning programme, workshop (in the form of word-association exercise -WAE) and interview were employed. The various data collected was crystallised so as to present a credible, reliable and trustworthy findings that resonate in the central phenomena; that is learners' conceptual understanding of redox concepts.

The data obtained was processed and analysed using interpretive case study techniques and a systematic construction of themes.

1.9 Sample and the participants

Self-selection sampling procedure (Cohen, Manion and Morison, 2000: 102) was adapted for the research. I decided to embark on this research with the grade 11 science learners of my school since it is a small scale one and a case study.

1.10 Significance of the research

Oxidation and reduction reactions form the basics of many chemical processes. It is also an integral component of many topics in other science disciplines. Conceptual understanding of redox will enhance learners understanding of other related topics.

1.11. An overview of the chapters

Chapter 1 deals with an explanation of the background of the study, the context, the research problem, philosophy and the approach to the research.

Chapter 2 engages critically with literature on or related to redox reactions. Previous investigations carried out on the topic and the findings will be discussed and analysed.

Chapter 3 looks at the research paradigm, methodology the research design and the research techniques.

Chapter 4 deals with the analysis of the collected data. Findings and themes are constructed. In the analysis process, some direct examples from the learners are provided.

Chapter 5 consists of the discussions of the findings and emerged themes that were constructed. The trustworthiness of the study is also discussed.

Chapter 6 sees the researcher giving a brief account of the experience obtained in doing the research.

1.12 Conclusion

This chapter has presented an introduction to the study with regard to its context, aims and the research questions. The problem of this inquiry was elucidated, emphasising the importance of using practical activities and real-life issues in the teaching and learning of redox reactions and for that matter science. In the next chapter, I will review literature related to the topic of investigation.

CHAPTER 2

LITERATURE REVIEW

> "In order for learning to take place, the pupil must understand the new material presented in terms of existing cognitive structure. And for this to happen, it is necessary both for the learner to hold some relevant prior knowledge and to 'make the connection', i.e. to recognize its relevance. If neither of those conditions are not met, then no meaningful learning will take place" (Taber 2001: 160).

2.1 Introduction to the chapter

The discussion in this chapter focuses on the nature and structure of the South African educational system, where education has come from, where it is now and where it is heading. I also examine the philosophies and educational theory that supports the various systems of education.

Also in this chapter, I examine the important role learners' prior knowledge plays in the educator's planning, and how prior knowledge affects new experience. Furthermore, I discuss the use of practical activities to stimulate, challenge and develop curiosity in learners on the research unit. Finally, a discussion of previous investigations conducted on the topic being researched and the influence of their findings on my research.

2.2 Background - Theory, Philosophy and Methodology in Education

The knowledge base of the global community is evolving at an extraordinary pace and new technologies are revolutionising education, as educational systems in several countries, including South Africa, are undergoing transformation. Kyle (1996 cited in Hodson, 2003: 645) contends, "Education must be transformed from the passive, and apolitical orientation that is reflective of most student's school-based experience to an active, critical and politicized life-long endeavor that transcends the boundaries of classroom and schools"

The transformation in education has seen an overwhelming paradigm shift from a behaviourist towards a constructivist that underpins the Outcomes-Based Education. The role played by learners and teachers is crucial and at the heart of this dynamic system of education. The concept of the venerable old master teacher is difficult to sustain in an educational context of new methodologies and new curricula. The motivation from the discussion above leads me to have a closer look at the theories underpinning the 'old' and the 'new' curricula.

2.3 Behaviourism - the theory underpinning the 'traditional curriculum

Before the introduction and implementation of Outcomes-Based Education, South African education was dominantly driven by the behaviourist philosophy and pedagogical dictates which I may refer to as the 'traditional model' of delivering information. Pollard and Liebeck (1994: 70) argue that behaviourism is a theory that analyses behaviour and is simply a learned response to external stimuli. This view is re- iterated by van Harmelen (1995: 53) that human behaviour is determined by the rules that govern our interaction with the environment.

However, despite the emphasis on the influence of the environment on human behaviour promulgated by the behaviourist, learners' interaction with the environment seems to exist in theory. Seemingly, teaching and learning in this paradigm in practice ignored the important role the environment plays on learners' behaviour. On the other hand, the previous educational system upheld the view expressed by Ozmon and Craver (1986: 181) that behaviourism holds the promise that we can become anything through proper behavioural engineering, stressing the behaviourist belief in the schemes of things as "orderly, regular, predictable and hence controllable". I believe this formed the basis of the traditional curriculum. For example, in some schools there are rules and regulations, which are in place to streamline the behaviour of the learners. These make the learners behave and think in a particular way.

Some aspects of the research was underpinned by this theory however, the process was predominantly conducted in the constructivist paradigm discussed in the next session.

2.4 Constructivism – the theory underpinning the New Curriculum

Transformation in Education led to the introduction and implementation of the new curriculum underpinned by the Outcomes-Based Education (OBE) philosophy with an accompanying pedagogy based on social constructivist theoretical frameworks.

According to the constructivist theory "true knowledge can only exist when it is constructed within the mind of a cognising being" (Etchberger & Shaw 1992: 411). Though it (constructivism) does not regard facts as unimportant, it maintains that knowledge is the sense that we make of the facts or information (Hinchey 1998: 45). Von Glassenveld (1987: 15) also echoes this idea when he states that "facts are *made* by us and our way of experiencing, rather than *given* by an independently existing objective world". Furthermore Larochelle (2000:62) maintains that, "it is impossible to have an all-encompassing view; holding a point of view is a matter of choice". Hinchey (1998: 45) also supports this view when he claims, "all knowledge is a matter of human interpretation". I believe this is the driving force behind the new curriculum and this is what interests me most about the new curriculum.

The new curriculum embraces Piaget's argument that knowledge is constructed as the learner strives to organise his or her experiences in terms of pre-existing mental structures or schemes (Bodner 1986: 873). The child must therefore, be allowed to create his or her own structures. This is an essential component of the new curriculum.

One other important aspect of constructivism, which reflects widely in the transformed curriculum was the view expressed by Bruner and Vygostky (cited in Bennett & Dunn 1994: 52) that social setting plays an important role in the acquisition of knowledge as such... "it is not just that the child who must make knowledge his own, but that he must make it his own in a community of those who share his sense of belonging to a culture". Summarising all that constructivism has to offer (which is arguably the bedrock of the OBE philosophy), van Harmelen (2000: 9) has this to say: "The way that knowledge is perceived and conceived in learning environments where knowledge is accepted as being socially constructed, implies that the relationship between teachers and learners must of necessity be based on mutual respect. Where there is mutual respect, both learners and teachers are empowered through the development of knowledge in a participatory environment". My research will take this route. The discussion that follows is curriculum change – internationally and nationally.

2.5 Curriculum Change – Internationally and Nationally

Although constructivism as theory is argued to be laudable with many things to offer, it does have its weakness. However it has become like a strong wind blowing across education in many countries, causing curriculum restructuring and review. According to Millar (1996: 7), curriculum in the United Kingdom (UK) has been reviewed and restructured with constructivism as the underpinning theory to encourage understanding of concepts and relating the classroom to the society. Gott and Duggan (1996: 801) mentioned the restructuring of curriculum alongside the implementation of a national curriculum for new vocational qualification in science and science related subjects in England and Wales lacked explicit recognition of a knowledge base and a guide to the teacher. Pliska and McQuade (1994: 66-69) and McGhan (1994: 70-72) reveal that OBE has not received universal and unequivocal acceptance and support in countries where it has been implemented. For instance, in the United States (US) vociferous leaders, both professionals and laymen and especially church leaders, have been reported as being against the reform and the role of OBE *(ibid)*. Gardner (1999: 58) links OBE unequivocally with a behaviourist psychology, despite its constructivist epistemology. Galbraith, Carss, Grice, Endean and Warry (1997: 447 – 467) write on the curriculum change in Australia with areas such as literacy, numeracy and science receiving special attention.

In the South African context, curriculum 2005 (C2005) is modelled on outcomes-based education (OBE) principles, and incorporates many practices that have gained favour worldwide, such as child-centred learning and continuous performance-based assessment (Rogan and Grayson 2002: 2). Reiterating this view and finding the origin of OBE in South Africa (SA). Christie, (1995: 4) claims that the immediate origin of OBE in SA is in the competency debate followed in Australia and New Zealand. However, Jansen (1997: 1) argues that OBE does not have any single historical legacy.

2.6 Outcomes Based Education in South Africa

The new curriculum underpinned by OBE philosophy, being implemented in South African schools has as its focus the outcomes of teaching and learning and the development of skills. Thus require of teachers to exhibit a high level of determination, creativity, commitment and competence, amongst other qualities. This was evident throughout my research process. I will argue that these requirements are not being practiced in many classrooms (evident in my working environment and discussions I have with fellow educators). In my view, for an effective implementation, geared towards achieving the desired objectives of the National Curriculum Statement, teachers need to undergo 'competency-based teacher education'- a reaction against the shortcomings of the traditional teacher-development programme (Zeichner, 1993: 5). The new curriculum purports to develop attitudes, skills and behaviours that facilitate intellectual, social, emotional and physical growth in learners (Weber, 1972: 12) geared by teacher change and competency. A desire I wish to accomplish in this research project.

I believe that with adequate continuous professional development and high levels of competency developed, creativity and critical spirit, driven by resourcing the institutions, the underlying principle of the outcomes-based education could be achieved. My research process suffered a little due to inadequate resources in my school.

Though the expectations of the national curriculum statement (NCS) are laudable, it has its pitfalls. Jansen (1997: 1 - 9) outlined flaws in the OBE implementation, which he believes will contribute to the failure of the programme as follows:

- The language innovations associated with OBE is too complex, confusing and sometimes contradictory. For instance 'critical outcomes' and 'specific outcomes' are used interchangeably, which is confusing.
- OBE is based on flawed assumptions about what happens inside schools, how classrooms are organised and what kind of teachers exist within the system. This for instance has compelled the education officials to organise regular in-service professional development programmes for teachers and make regular visits to schools to acquaint themselves with first-hand difficulties of the programme.
- The management of OBE will multiply the administrative burdens placed on teachers. Yes, this is happening and teachers are finding a way to deal with it. However, the efficiency of the teachers is questionable.
- SA schools do not have the database to collect information on the children and their families. For instance, there is no computer in my school as such all data on the learners has to be captured manually.

Yes, there are problems with OBE, but does it mean that we should 'throw the baby out with the bathwater'. As such Jansen's criticism, I believe guided the advocates of OBE to restructure the programme. Rasool (1999: 237) also expressed this view that "Jansen's presuppositions enrich the curriculum debate by adding a sense of realism to it". He further admits that the strength of Jansen's article lies in the fact that it exposes the stark reality that the new curriculum is not without limitations. This, I believe, has contributed to the regular review of the new curriculum and subsequent introduction of the RNCS.

The review of the new curriculum is reflected in the new national curriculum for Further Education and Training (NCS for grade 10 – 12 schools 2002: 3) for all specialised subjects including physical science. The scope for physical science, as proposed in the NCS (NCS Physical Science 2002: 11) shaped my understanding of the NCS, which I applied in the research process. The useful skills envisaged include observation, comparison and measuring, classifying, inferring, predicting, communicating, designing/development and experimentation, controlling variables interpreting, formulating models and acquisition of reflective skills. This can be done by regularly assessing the learners' achievements as learning proceeds.

According to Pahad (1999: 267), teachers are to track down each learner's progress in relation to his/her development along a learning continuum. Feedback to the learner must be positive, constructive and developmental, motivating learners towards higher achievement. Also, a non- threatening atmosphere should be created to encourage learners to be active participants in lessons. All these demands make the task of today's science teacher enormous, calling for a new approach to teaching and learning science, taking into account the demands of the new curriculum.

The achievement of these objectives seems to be elusive due to the fact that many teachers lack experience with inadequate continuous contextual professional development and possess inadequate resources and a poor understanding of the expectations outlined in the new curriculum. At the tail end of all these expectations comes assessment, which is a critical element of any curriculum. Assessment, I will define as a process of collecting and interpreting evidence collected at different times and places using various methods, instruments, modes and media in order to identify learner's strengths and areas for further development. The old curriculum placed a lot of emphasis on summative, assessment in determining the level of achievement or competency of a learner. The new curriculum on the other hand, transcends additional approaches to assessment of learners (Revised

National Curriculum Statement: 93 –96) because its proponents believe that learning and assessment are inextricably linked.

The physical science curriculum went on further to outline additional methods of collecting assessment evidence. These are observation-based, test-based and task-based (NCS Physical Science, 2002: 35). The teacher alone no longer assesses the learner, but also includes the learner and his/her friends or classmates in the assessment process. The new curriculum further stresses the importance of learners working in groups, sharing ideas, cooperating and assisting one another and could include assessment by other groups to find out if the co-operation exists in the group. This approach, however, has its weaknesses, which I have identified as:

- Some learners may become observers instead of being active participants (fold their arms and let others to do the work).
- Some members of the group may be domineering (disregard the views of others).
- Noise usually accompanies this process (interaction with group members may be chaotic).
- In some cases, there is an over emphasis on group work at the expense of individual task. I feel a balance should be struck. I will argue further that learners should be encouraged to reflect on old experiences whilst exploring new ones.

2.7 Understanding and Prior Knowledge

To evaluate understanding in my opinion is something I believe will be very difficult. To teach towards understanding requires a view of what it means to learn with understanding and how this differ from learning without understanding. According to White and Gunstone (1992: 57),

> "Understanding of a concept of a discipline is a continuous function of the person's knowledge, not a dichotomy and is not linear in extent. To say whether someone understands is a subjective judgment, which varies with the judge and with the status of the person who is being judged. Knowledge varies in its relevance to understanding, but this relevance is also a subjective judgment".

Therefore, to declare or place emphasis on understanding, as purported in the NCS, seems difficult to achieve. However one dictate emphasized in the Revised National Curriculum Statement (2002: 93 – 94), which I believe plays a very important and valuable role in learning is the probing of prior knowledge, perceptions and experiences. Prior knowledge amongst others, determines what we learn from experience and experience helps us to consolidate and build on our prior knowledge. In order to make the most of any new experience gained by learners, the elicitation of prior knowledge and how it affects learning need to be examined. According to Roschelle (2003: 1), findings revealed that learning proceeds primarily from prior knowledge and only secondarily from the present material. Appleton (1993: 269) posits that learners come to the learning situation bringing all of their previous experiences, which are arranged into schemata or mini-theories: a mix of cognition, feelings and skills. A learning experience commences with some new encounter, which the learner interprets and makes sense of in terms of his/her existing cognitive structure. The classroom context of the learning experience influences, which schemata of the learner's cognitive structure are used to interpret the experience (Claxton, cited 1990 in Appleton 1993: 269), both in terms of which sensory input to attend to, and which memories are activated in order to construct meaning for the experience. Piaget (1978 cite in Appleton 1993: 269) points out that in the process of assimilation, the learner will perceive that either existing schemata provide adequate explanation for the experience or there is some inadequacy in the schemata such that the experience cannot be fully explained. Strike and Posner (1985 cited in Roschelle 2003: 3) argue that prior knowledge forces a theoretical shift to viewing learning as conceptual change. Prior knowledge, if ignored, may be at odds with the presented material and consequently lead learners to distort presented material. Also neglect of prior knowledge may cause learners to learn something different from the educators' intentions, no matter what those intentions are.

In fact, I consider prior knowledge as the cradle of the construction-adsorption model of learning, since new knowledge is constructed from the old. We often claim that eliciting prior knowledge is critical, however incorporate it in our teaching becomes difficult.

Prior knowledge has diverse and pervasive influences on learning. As such it is important to cultivate sensitivity to the different points of view that the learners bring to an experience. One must therefore, look, listen and observe closely as learners use materials or respond to issues. Most often, it becomes difficult to teach new experience effectively without recognising the previous experience of the learners. Glasersfeld (1984: 76) emphasises that prior knowledge influences learning, and that, learners construct concepts from prior knowledge. I would like to mention that new experience (knowledge) does not replace prior knowledge; rather new knowledge makes use of prior knowledge. An issue investigated in this research project.

Let me also mention that prior knowledge may sometimes lead learners to adopt unconventional interpretations of concepts (This became evident when I elicited my learners' prior knowledge on oxidation and reduction reactions). In such a case, prior knowledge must be confronted, challenged, and restructured in order for new knowledge to take its place.

Roschelle (2003: 20) contends that understanding prior knowledge is 90% perspiration and 10% method. Standard tests (empirical approach) offers limited perspective of learners past experience because they are almost always written from the perspective of the expert. Instead, it is crucial to get learners to talk and then pay careful attention to what they say and do. Roschelle (2003: 20) again points out three specific (modern and sophisticated) methods from the research community, which he claims can be helpful. These are:

- Clinical interviews: Posner and Gertzog (1982: 198) suggest that clinical interviews usually involve a task in which the learner manipulates some physical material. This is then followed by a series of questions to probe the learner's understanding and to obtain the learner's prior knowledge.
- Think-aloud problem solving: Within the framework of 'think-aloud' problem solving, Robertson (1990 in Roschelle 2003: 20) has this to say. "The learner is trained to 'think aloud' while they perform on a simple task". The interviewer does not ask questions, but merely prompts the learner to "say what you are thinking" whenever the learner stops talking. The process is recorded, transcribed and analysed for evidence of prior knowledge.
- Video interaction analysis: This technique has to do with a small group of learners performing a task under the watchful 'eyes' of a video camera set on them constantly. The tape is then reviewed with the learners for interpretation and analysis of prior knowledge. (Roschelle and Goldman, 1991 in Roschelle, 2003: 20).

The clinical interview technique, which suits my research topic, was employed. I also engaged a series of 'hands on' activities, including 'self investigation' (open investigation) and 'practical activities' to evoke learners' mental schemata (prior knowledge). Practical activities play a very important role in science teaching. This is pronounced in the NCS (Physical Science, 2002: 9), which says that "practical activities for learners must stimulate curiosity, deepening learners' interest in the natural and physical world they live in, bringing them to reflect on and question their role in the universe". It could be inferred from the above that there is a belief that skills are developed in the process of doing practical work. This may not be all that is required, however, as Gott and Duggan (1996: 799) point out, it is from an understanding of scientific evidence, rather than simply from knowledge of facts and concepts of science (substantive knowledge), that the questionable practices and conventions can be challenged. I believe that practical activity, if well structured, could enhance the understanding of scientific knowledge, which if revoked or translated does become instrumental in everyday life as such practical activities could serve as a bridge between scientific content and everyday scientific events. Although I uphold and regard practical activities as having a key role in the teaching of scientific evidence, their value could only be relevant if the type of activity is selected with care and with clear purpose in mind.

Practical activities constitute the basis of this research due to the following reasons:

- To probe learners' prior knowledge and to determine learners' conceptual understanding.
- To stimulate and sustain curiosity and an interest in and enjoyment of the unit under investigation.
- To promote interest in and awareness of, and as far as possible an understanding of the social, economic and environmental implication of the topic investigated.
- To encourage learners to bring their environmental knowledge into the classroom situation and vice versa.
- To promote understanding of the investigated unit and to stimulate learners to relate the outcomes of the activities with some happenings in their communities with understanding.
- To promote the skills of observation, experimentation, processing, analysing and interpretation of data.
- To encourage learners to integrate the unit investigated with other topics in other specialized subject area.

I believe that practical activities challenge learners to be a part of the dynamism taking scientific concepts by storm, with new developments, innovations and challenges erupting every day. It will also promote a better understanding of scientific concepts and equip learners' to face the enormous scientific challenges ahead. I considered the topic (oxidation and reduction reactions – redox) investigated to be one that could stimulate these qualities.

2.8 Oxidation and reduction reaction

Most of the research literature on chemistry I have read demonstrates a great deal of concern for learners' conceptions in chemistry. The majority of such work exposes the nature of learners' knowledge, perceptions and misconceptions held in many topics in chemistry. These indicate that learners perceive the most difficult topics to be chemical equilibrium, the mole, redox reactions and reaction stoichiometry. Oxidation and Reduction (redox) reactions in particular appear to be the most difficult and are also perceived by most learners as one of the most difficult units in chemistry (Ringes 1995: 7) drew the attention of many researchers producing a substantial amount of data. Most of the research conducted however, emphasises the difficulties learners have in understanding the underpinning concepts of redox reactions. Only very few investigated the effect of learners' prior knowledge on understanding these underpinning concepts. I consider redox reactions to be one of the most important units in chemistry, as it links with other topics in other science disciplines such as biology and physics. As such my focus is geared towards investigating (probing) learners' prior knowledge, perceptions and experience as factors contributing towards learners' understanding of the concepts of redox reactions.

Soudani, Sivade, Cros and Medimagh (2000: 64 – 72), in their investigation of learners' ability to use their theoretical knowledge of redox concepts to interpret natural phenomena of everyday life had this to say "students have difficulties in recognising the scientific nature of well-known everyday phenomena" which is an indication that scientific concepts are learnt in isolation and not related to real life situations. They furthered their study to identify the nature of difficulties learners have in understanding redox and electrochemistry concepts. The research questions investigated by Soudani *et al.* (*ibid*: 68) include:

- What kind of words came into the minds of learners when presented with certain terms such as oxidation and reduction?
- What distinction or categorisation do learners make when confronted with groups of scientific phenomena, involving redox, among other concepts such as acids and bases, precipitation and dissociation, with no chemical equation or formula?
- What criteria do the learners use in making this distinction?
- Do they (learners) encounter difficulties in doing that?
- Are the learners capable of using their theoretical knowledge to interpret everyday phenomena?

In answering these questions, Soudani *et al.* (2000) settled on a summative assessment tool using three techniques namely;

- Word Association Test (WAT)
- Multiple – choice questions (MCQ) and
- Open questions (OQ).

They found out that the percentage of incorrect responses was higher than the correct ones (what they consider to be a correct response is relative in my opinion, since they focused on specific responses only). And also, common sense is a predominant factor in learners' minds, which constitute epistemological obstacles (the role of perception taking its toll). They also claim that learners refer to superficial perceptual details to explain scientific phenomena, neglecting their theoretical knowledge (the conceptual reality). Furthermore, Soudani *et al.* (*ibid*) assert that learners use theoretical knowledge when required in examinations, but they fail to use this same knowledge, and still retain common everyday explanations, when dealing with everyday situations.

A close scrutiny of the research tools employed by Soudani *et al.* *(ibid)* reveal that in an attempt to investigate understanding of concepts, they investigated how best learners could recall redox concepts and relate it to everyday phenomena. In fact the teaching of redox is dominated by the abstract, the algorithmic and numerical problem-solving aspect. The reality is that teaching of redox ignores the learners' needs to comprehend the world and insists on quantitative learning rather than qualitative understanding. Even though I agree with their findings, I consider the research techniques employed to have provided insufficient connection between the learners demonstrating understanding and perceptions in that learners were not required to make chemical interpretation of everyday phenomena, nor to consider the relationship between biological phenomena (photosynthesis and respiration), natural occurring systems (rusting) and chemical concepts (lead-acid accumulators).

Preceding the Soudani *et al.* (2000) investigation was Ringnes' (1995: 74 – 78) study on grade 12 learners' in Norway, which focused on their learning difficulties and misconceptions of redox reactions. He substantiated his hypothesis by investigating these questions.

- *Problem 1* - Learners were required to define oxidation, write an equation to support their definition and mention the substance, which has undergone oxidation.
- *Problem 2* - Learners were give the equation:

  $$2K_{(s)} + H_2O_{(l)} \longrightarrow 2KOH_{(aq)} + H_{2(g)}$$

  and asked what type of chemical reaction this reaction equation is an example of?

Linked to these questions were the difficulties learners have in associating the four models of redox reaction namely:

- The oxygen model
- The hydrogen model
- The electron model and
- The oxidation number model.

The research technique they employed in gathering data was summative assessment. Ringnes (*ibid*) considered the definitions of a concept to explore the essential meaning of the concept. I believe that in an attempt to verify learning difficulties of learners they succeeded in challenging the learner's ability to regurgitate what had been memorized. I consider that the use of models in chemistry, and redox models in particular, could challenge understanding, and as such expose difficulties learners have in understanding scientific concepts.

Ringnes (*ibid*) came up with the finding that, the old models (oxygen, hydrogen and electron models) have enormous limitations, which is consistent with Van der Werf's (1945: 218) suggestion of numerous inconsistencies in the electron model and the superiority of the oxidation number model, which I agree with. I also support the view expressed by Ringnes (1995: *ibid*) that the concept of redox should be given a thorough linguistic, historical and chemical presentation. As a new and more sophisticated model is introduced, the advantages of the new model and the limitations of the other model previously taught should be stressed. By such an approach backed with physical involvement (practical activities), learners would experience that scientific concepts are human constructions and that progress in science is not just an expansion of knowledge, but also requires modification, revision and even abandoning prior ideas.

Correspondingly, Garnett, Garnett and Treagust (1990: 150), in their research finding posit that all learners who correctly identified redox reactions applied the oxidation number concept (model). On the other hand, learners using one of the three other models of redox reaction manifested several misconceptions. Although most of these researchers applaud the oxidation number model, it is my opinion that if all these other models are well explored and learners helped to construct understanding of these by means of developing activities that encourage construction of knowledge, learners would be in a position to demonstrate the circumstances under which these other models could be helpful and enhance conceptual understanding of redox reactions. I further argue for an approach of using a plurality of models because of the utilitarian value of each model at different levels of education and when applied to different types of reactions in chemistry. Literature motivates researchers to explore difficulties and find antidotes to these problems and situations. My research intends to find antidotes to the problems faced by these researchers.

2.9 Conclusion

In this chapter, I have delved into related literatures that guide my research project. The work done by other researchers in this topic has been critically engaged with. The strengths and weaknesses of the reports presented were thoroughly digested and analysed to form a supporting base for my research. The task now is to discuss the methodological policies and assumptions for the research. Secondly to explore how these policies and assumptions could be applied to produce the research report.

CHAPTER 3

RESEARCH PROCESS AND METHODOLOGY

> "We are entities who are capable of monitoring our own performance. Further, because we are aware of the self-monitoring and have the power of speech, we are able to provide commentaries on those performances and to plan ahead as well. Such entities it is held, are much inclined to using rules, to devising plans, to developing strategies in getting things done the way they want them doing" (Harre' and Secord, 1972 cited in Cohen et al. 2000: 21).

3.1 Introduction to the chapter

This chapter discusses the design and methodological processes employed in the investigation, which has been guided by the research questions. The research format followed in this study is in respect of methods of data collection, relevant data processing tools and how the data was coalesced, consolidated and interpreted. Furthermore, this chapter aims at providing a framework of how the investigation was conducted.

3.2 Research process

One of the central themes of this study is to create a research process that would challenge learners to integrate their prior knowledge of biological, natural, man-made and environmental processes, demonstrating understanding of scientific principles and making learning *emergent* and *enabling,* rather than *imposed* and *engineered.* In order to locate the methodology and the research design of this study within the socio-historical framework of the unit, the following became the questions informing the choice of methodology, research design and data collection methods:

- What important role does learners' prior knowledge, preconceptions, perceptions and experiences play in their understanding of oxidation and reduction reactions?
- How do learners' prior knowledge, preconceptions and experiences enhance or inhibit their understanding of the concepts of oxidation and reduction reactions?
- How do different tools and strategies help develop learners conceptual understanding of redox reactions

Robottom and Hart (1993b: 594 cited in Lotz, H. 1997: 78) express the view that "different approaches to educational research... do not simply represent different strategies for data collection, but rest on and express different ideologies and replicate different political arrangements and relationships among teachers, learners, subject matters, and researchers themselves". With this in mind, I established approaches to the research considering methodology in terms of ideology rather than in the simply technical terms of method and technique.

3.3 Methodology

Methodology provides the theory behind the cluster of techniques that comprise a research method. Fein (as cited in Lotz 1996:77) notes that "methodology provides the philosophical framework that guides the research activity" and methodology is described by Van Manen (1975: 27) as comprising 'the fundamental assumptions' about the 'general orientation to life, the view of knowledge, and the sense of what it means to be human' that direct the particular mode or method of enquiry in a study. Janse van Rensburg (2001: 1) in contributing to this view, asserts that methodology refers to philosophical assumptions, values and theories, which inform and support (underpin) the way in which a particular research method is used. This then means that methodology involves the research design, data collection (including techniques), data analysis, and theoretical backings together with the social, ethical and political issues of the study.

The methodology adopted for this investigation is **Interpretive**. Erickson (1998: 1155) contends that an interpretive methodology is concerned with "human social actions and opinions that are locally distinct and situationally contingent". As such, I was interested in the meaning the learners make of the phenomena involved in the unit under investigation (redox reactions). I also subscribe the Hegelian view mentioned in Janse van Rensburg (2001: 16) that meaning (and therefore knowledge generated through research) is constructed by individuals and groups, in interaction with each other through communication. Also, Janse van Rensburg (2001: 17), claims that "interpretivist researchers are often not that interested in taking action through or even after their research; their focus is on unravelling the complexities of social life as they and the research participants experience it". The research design falls within the domain of the above statement and furthermore, reflects an interest in contextual meaning - making and conceptual understanding, rather than generated rules. The research looked for rich, detailed information of a qualitative nature through in-depth questionnaires, practical activities, audio-visual observation workshop and an interview.

As an interpretive researcher, I did not analyse relationships between variables, but instead, made meaning of meanings encountered through the process, during which I put myself 'in the shoes' of the learners. With the above-mentioned emphasis on interpretive dimensions, I located my research within this paradigm by concentrating on the case study.

3.4 The research design

I consider a research design process to be analogous to a draughtsman's building plan. The choice of a specific design is determined by how the problem is shaped by the questions it raises and by the type of findings desired.

According to LeCompte and Preissle (1993: 55), research design involves putting things together, bringing to consciousness and to the notebook as many aspects as possible of the researcher's planning and preparation for the investigation. It is a plan for assembling, organising and integrating information (data) and it results in a specific end product (research findings). It is a method that is able to catch the complexity of a case or situation (Stake, 1995: xi).

This research sought to probe the conceptual understanding of my learners of oxidation-reduction reactions using environmental occurrences and situations and relating it to the classroom and the impact of classroom knowledge associated with the environmental and natural happenings. The research involved a single instance (a class). Taking into account the above, I was further encouraged to conduct the research as a case study, which also provided the platform to ascertain in real life the problems learners face in developing conceptual understanding of the unit investigated, using various activities rather than presenting them with abstract theories or principles.

Hitchcock and Hughes (1995: 322) posit that a case study approach is particularly valuable when the researcher has little control over events. They further (*ibid*: 317) consider that a case study has several hallmarks which happens to relevant in my research project since learners were allowed to explore the issue, especially the importance of integrating prior knowledge into new experience.

The view of Eisner and Peshkin (1990: 29) is that a case study puts an emphasis upon "practice, participation, reflection and interpretation". With this in mind, the investigation was conducted in a participatory mode engaging learners in a series of practical activities conversations, discussions, debates and a workshop.

Nisbet and Watts (1984 cited in Cohen *et al.* 2000: 184) identified several strengths of case study as:

- The result being more easily understood by a wide audience (including non-academics) as they are frequently written in everyday, non-professional language.
- They are immediately intelligible; they speak for themselves.
- They catch unique features that may otherwise be lost in larger-scale data. These unique features might hold the key to understanding the situation.
- They are strong on reality.
- They provide insights into other similar situations and cases, thereby assisting interpretation of other similar cases.
- A single researcher can undertake them without needing a full research team.
- They can embrace and build on unanticipated events and uncontrolled variables.

These numerous strengths amongst other reasons motivated me to conduct the investigation within a qualitative case study framework.

Creswell (1994: 2) defines a qualitative study as an "inquiry process of understanding a social or human problem, based on building a complex, holistic picture, formed with words, reporting detailed views of informants, and conducted in a social setting". This is indicative that qualitative research is in fact concerned with the meaning of human behaviour and experience and the function of social functions. In other words, how people make sense of their lives, what they experience, how they interpret these experiences, and how they structure the social world (Silverman, 1993: 24). With reference to this inquiry, the social world of the learners is located in the conceptual understanding of oxidation–reduction reactions.

According to Leedy (1997: 156) qualitative research has grown out of diverse disciplines (anthropology, sociology, psychology) that are marked by distinctive interests, theories, issues and research methods. However, in education research, I believe its use follows the dictates of research in psychology and working with pre-determined grouping of participants' responses. Thus in my view, qualitative research appears to be constructivist and interpretivist in its epistemology (a framework within which this inquiry is conducted).

Miles and Huberman (1994: 10) posit that qualitative data serve not only as a good basis for discovering and developing hypotheses (if the unit of analysis invites such a hypothesis) it provides an in-depth description of how the discovery and hypothesis is developed.

I must, however, indicate that qualitative methods have their limitations, shortcomings, and problems. Erickson (1986: 140) lists four types of problems that are: inadequate amount of evidence; inadequate varieties of kinds of evidence; inadequate attention to disconfirming evidence and lack of attention to discrepant cases, which can occur because of poor procedures in qualitative research. These pitfalls contributed towards the structuring of my research tools.

3.5 The research method and techniques

I will define method (within the framework of this research project) as an overall plan for the orderly investigation of the research unit, no part of which contradicts, and all of which is based upon, the selected approach. However, with one approach there can be many methods. Technique, on the other hand, is implementational – that which actually takes place in a classroom. It is a subterfuge used to accomplish an immediate objective (Anthony, 1963: 63 – 67 cited in Richards and Rodgers, 1995: 176). Techniques must be consistent with method, and therefore in harmony with an approach as well (*ibid*).

3.6 The research tools

All research involves the collection and analysis of data, whether through documents, measurement, questionnaire, observation, interview or a combination of these or other strategies. The data collected during and for a research project may, however, vary considerably in their characteristics. Blaxter, Hughes and Tight (1997: 141) suggest that:

- Data may be numerical, or verbal, or may be a combination of the two.
- Data may be 'original', in the sense that the researcher might have collected information never before collected; or may be 'secondary', already put together by somebody else, but reused, perhaps in a different way, by the researcher.
- Data may consist of responses to a questionnaire or interview transcriptions, notes or other records of observations, experiments (practical activities), documents and materials, or of all these.

My research data falls within the domain of the third suggestion. The tools employed to collect data seeks to encourage the learners to transfer knowledge from outside the classroom (environment) to the classroom and vice versa. Against this background, the research tools used for data collection were:

- "Open investigation" (Projects)
- Practical activities
- Questionnaires/worksheets
- Workshop/Audio-visual observation with word association exercise as the technique and
- Interview

3.7 Open Investigation

The open investigation served as the introductory data collection tool. Learners were given a set of instructions, on the basis of which they decide on their research topic for investigation. The framework served as a guide, very flexible and open, such that the participants were free to explore whatever aspects were applicable to the central theme.
The purpose of giving the participants the opportunity to embark on a research project (open investigation) is twofold.

- To elicit the learners' prior knowledge of the unit under investigation (redox reactions)
- For the learners to demonstrate their conceptual understanding of project given to them.

I believe that the 'open investigation had a particular advantage because it allowed the learners to carry out a whole task with the autonomy to follow their own ideas and structure their own practical work. It provided an opportunity for them to put into practice the relevance of prior knowledge, organisation and application of prior knowledge.

Furthermore, the participants could demonstrate their understanding and apply ideas about evidence from their community on redox reactions. It sought to refine prior knowledge, prepare the participants for a long term learning process and to encourage them to engage their knowledge with real life situations related to the unit under investigation. Secondly, the learners' investigative task was initiated to prepare the participants to take part in the unit of investigation (redox reactions) with an external motivation (the investigation and findings were their own effort), thus bridging the gap between what they learn in the classroom and what occurs in their immediate surroundings.

It also served to challenge their organisational, cognitive and manipulative skills as well as preparing them for the research project.

3.8 Practical Activities

Another form of approach employed in this study to evoke the participants' prior knowledge and developing conceptual understanding was practical activities. I am of the opinion that practical activities can encourage the participants to think critically about the credibility and trustworthiness of their evidence and to relate their evidence to real life situations. In so doing, their mental image of science as an abstract subject will give way to science as real life experiences. This view is also express by Wilson and Stensvold (1988: 350), who say that: "practical activities fulfil the need for learners to experience and learn science in a real-world setting".

Against this background, I will argue that practical activities could be an essential tool in eliciting the participants' prior knowledge and determining their level of conceptual understanding of the unit under investigation.

3.9 Questionnaire

The questionnaire was used to further investigate the participants' prior knowledge and to probe deeper into the report on their research project, I administered the questionnaire completed by the participants. All the questionnaires distributed to the learners were returned, though only a few of them (participants) responded to all the questions, and the others responded partly. An interview was organised as a follow-up on the questionnaire.

A questionnaire, as described by Irwin (2002: 4) is "a series of questions set out on paper, and to be answered on paper rather than verbally". Irwin (2002: 7) further argues that this potential flexibility lies in the way in which the questionnaire is designed and constructed (layout, types of questions and sequencing of questions, appropriate language and clear instructions). This was very relevant in the structuring of my research questionnaire and worksheets.

However, the use of questionnaire has its ethical implications and demands. Cohen *et al.* (2000: 245) asseverate that the questionnaire will always be an intrusion into the life of the respondents, be it in terms of time taken to complete the questionnaire, the level of threat or sensitivity of the questions, or the possible invasion of privacy. As such care was taken to minimise this intrusion.

The worksheets were designed to identify the strengths and weaknesses of learners' conceptual understanding of redox reactions during practical activities.

The research questionnaires and worksheets were structured bearing in mind the requirements, dictates and demands of the semi-structured questionnaire procedure (Cohen *et al.* 2000: 248 - 249). I considered open-ended questions to be convenient for the research, since it is a small-scale research project involving a single case.

In order to increase credibility and trustworthiness, the questionnaires were pilot tested. Wilson and McLean (1994: 47) and Cohen *et al.* (2000: 260) argue that pilot testing a questionnaire serves:

- to check the clarity of the questionnaire items, instructions and layout.
- to gain feedback on the validity of the questionnaire items, the operationalisation of the constructs and the purposes of the research.
- to eliminate or minimise ambiguity and difficulties in wording.
- to gain feedback on the type of question and its format (open-ended).
- to gain feedback on the layout.
- to check whether the questionnaire is too long, short, too easy, or too difficult, too engaging, too threatening, too intrusive, too offensive or too demanding.

A few of the above came to light and were rectified.
In brief, as Oppenheim (1992: 49) remarks, "everything about a questionnaire should be piloted". This was extended to all data collection tools as well.

3.10 Audio-visual observation workshop

The purpose of the video recording was to observe and capture the groups' performances and demonstration of understanding of the unit investigated. My focus was on word-association within the framework of the research project. The word-association exercise (WAE) replicates, to some extent, the word-association test (WAT) of Soudani *et al.* (2000: 6) in transferring knowledge from the classroom to the real world: in this case redox concepts. Soudani *et al.*

conducted their research using WAT as one of their principal tools in collecting data. However, in this study, the WAE only served to evoke prior knowledge and confirm understanding.

Klu (2000: 157) asseverates that video recordings extend the range and precision of the observations that can be made, increasing credibility and trustworthiness of the findings. Marshall and Rossman (1988: 86) contend that video recordings preserve activity and change in its original form and can be used in the future to take advantage of new methods of seeing, analysing and understanding the process of change and may repeatedly be analysed in a variety of ways.

Although video recordings may be intrusive and make the learners uncomfortable, it was useful in recording even the most minor details. To minimise the discomfort the presence of the video camera might cause, the participants were informed and several practice recordings done. I viewed the replay of the video recording several times in order to have an accurate transcription of what really transpired. I will argue that observation workshop data is attractive and interesting, as it afforded me the opportunity to gather 'live' data from 'live' situations. I was also afforded the opportunity to look at what was happening in *situ* rather than at second hand (Patton, 1990: 203 – 205). **Cohen *et al.* (2000: 313) share the same view when they posit that audio-visual observation method is a powerful tool for gaining insight into situations.** The aim of the workshop was to establish if the groups could classify terminologies exclusively under oxidation, and under reduction and under oxidation-reduction, illustrating them with real life examples.

3.11 Interviewing

Interviews constitute one of the essential tools in this research project. The purposes of using interviews include the following:

- To evaluate and assess the level of conceptual understanding achieved by the participants of the unit of analysis;
- To determine to some extent if the practical activities and use of environmental issues, amongst others enhance or inhibit participants conceptual understanding of the unit of analysis;
- To serve as a back up to, and clarification of, responses received from the participants;
- To gather information on the participant's opinions on the unit researched.

I used the semi-structured interview format. Merriam (1991 cited in Klu, 2000: 174) suggests that this format allows the researcher to respond to each situation as it arises, to the emerging world of the respondent, and to new ideas in the topic. This form of interview is also referred to as 'the elite interview' LeCompte and Preissle (1993: 241). That is, the researcher is not interested in statistical analysis of a large number of responses, but wants to probe the views of a small number of individuals. My interview situation was such that it allowed the respondents to talk freely and emotionally, which enabled me to have candid, rich, deep, authentic and honest feedback about their experiences.

In conjunction with other methods of data collection used in this study, the semi-structured interview serves to verify, establish and expatiate on the information obtained from the respondents of the inquiry.

Kvale (1996: 11) lucidly defining the interview as "an interchange of views between two or more people on a topic of mutual interests", sees the centrality of human interaction for knowledge production, and emphasises the social situation of research data. This explanation vividly suits the framework within which this research interview was conducted. According to Fontana and Frey (1994: 665), interviewing has a wide variety of forms and multiplicity of uses. They (*ibid*) contend that the most common type of interviewing is individual, face-to-face verbal interchange, which I employed.

3.12 The Setting

This study took place in a township school in the East London area of the Eastern Cape Province of South Africa. However, pilot testing of the research tools and strategies took place in a rural school, also located in the East London district.

The school where the research was done is very accessible, making it easy for education officials and other interested groups to visit the school regularly. It is government-control school, but the community involvement is a paramount attribute. The predominant language spoken in this area is Xhosa.

3.13 Sampling

The investigation was conducted with a class of 20 grade 11 learners comprising of four males and sixteen females. Most aspect of the study engaged the entire population, with the exception of the interview session. The size of the sample for the interview was determined by the researcher and the learners to ensure that the sample represents the wider features of the population with the minimum number of cases. Due to the gender imbalance as mentioned earlier, two boys and four girls volunteered to be interviewed.

Cohen and Manion (1985: 98) define a sample as "a smaller group or subset of the population in such a way that the knowledge gained is a representative of the total population under study". De Vos (1998: 191) quotes Arkava and Lane (1983) who define sample as "the element of the population considered for actual inclusion in the study". Vockell and Asher (1995: 170) also have this to say: "the term sampling refers to strategies that enable us to pick a subgroup as a basis for making references about the larger group". Also, Bieger and Gerlach (1996: 97) claim that sampling refers to choosing a portion of the target population for research, rather than studying the entire population. However, if the target population is sufficiently small and also accessible, it may be preferable to conduct the research using the entire population (as is my case).

3.14 Conclusion

In this chapter I have discussed the main tenets of the research in which the inquiry was conducted. I have illuminated the format of the study, methods of data gathering and analysis. In my opinion, conducting a credible and trustworthy research greatly depends on understanding the theoretical framework, the various components and their interrelated nature of the components of the research. This guiding principle helped in data collection and analysis discussed in the next chapter.

CHAPTER 4

DATA ANALYSIS AND FINDINGS

> "In qualitative studies, data analysis is best conducted as an early ongoing activity. This concomitant action on the part of the researcher allows the research design to emerge over time, suggesting the direction for subsequent data collection efforts" (Maykut and Morehouse, 1994: 123).

4.1 Introduction to the chapter

In this chapter, an overview of data collection tools and elemental activities, which make up data collection, is discussed and the different approaches to data analysis are also looked at.

Discussion is also made of how the data collected were transformed to make sense by developing themes.

4.2 Data Analysis

Freeman (1996: 91) defines data analysis as the process of drawing responses out of the data or finding them in the data. This means that to analyse is to find some way, or ways, to tease out what one considers as essential meaning in the raw data in order to reduce, reorganise and combine so that the readers share the researcher's findings in the most economical, interesting fashion. The product of analysis is a creation that speaks to the heart of what was learned (Ely, Anzul, Friedman, Garner and Steinmetz, 1991: 140).

As mentioned earlier, qualitative research involves almost continuous and certainly progressive data analysis from the start of data collection. Ely *et al.* (*ibid.*) asseverate that the process of analysis guides the researcher to focus and refocus observational and/or interview lenses, to phrase and rephrase research questions, to establish and check emergent hunches, trends, insights, ideas, to face oneself as research instrument. However, they indicate that the final phase of data analysis takes place when the researcher has left the field and sits alone. They said further that this is the time to begin tackling the question that has been in the back of the researcher's mind all along and it is time to 'tame the chaos' (volume of data collected). Blaxter, Hughes and Tight (1996: 183) ably demonstrate that the business of analysing data involves two closely related processes:

- Managing the data by reducing its size and scope, so that these can be useful and adequately reported on, and
- Analysing the managed set of data, by abstracting from them, and drawing attention to, what the researcher feels is of particular importance or significance.

4.3 Managing the data

Blaxter *et al.* (*ibid.*) elegantly present and discuss major approaches to the effective management of data:

- *Coding*- the process by which items or groups of data are assigned codes. These may be used to simplify and standardise the data for analytical purposes. Alternatively, the process may involve the reduction in the quantity of the data. This, to my understanding, implies that it is a procedure that disaggregates the data, breaks them down into manageable segments, and identifies or names those segments.
- *Annotating*- the process by which written (or perhaps audio or visual) material is altered by the addition of notes or comments. The process may draw attention to what one considers as a more significant section for abstraction and quotation. Then again it may serve as part of ones' continuing debate in order to refine and progress ones' ideas further.
- *Labelling*- where one has an analytical scheme (ideas or prejudices) in mind, or is in the process of developing one, therefore may go through materials such as interviews or policy documents and label passages or statements with significant words, which can then serve to direct further analysis.
- *Selection*- a key process in the management of data through which interesting, significant, unusual or representative items are chosen to illustrate one's argument.

These techniques could be used in conjunction with other techniques such as sorting, reducing, or summarizing the data from its original form (raw data), and getting it into a 'shape' more suitable for analysis and reportage. Coding and selection techniques were employed in managing the data collected, whilst the others served as guiding information.

4.4 Analysing the managed data

The focus here is on the ways in which the data collected and managed are transformed into a final product. I believe this to be the process whereby the researcher works to find a way to structure and communicate what was learned. And as such, it illuminates and extends the understanding of the phenomena investigated. Merriam (2001: 178) and Ely *et al.* (1991: 147) suggest that in order to of analyse the managed data one has to:

- Establishing categories- despite the fact that researchers manage their data, it is still important to establish a set of categories that arise from and make sense of the data. Creating categories helped me to organise the essential aspects of the responses from the participants after which I classified the data into some sort of schema consisting of themes.
- Developing themes – predominant in this analysis consist of inferred statement that highlights explicit or implied attitudes obtained from the responses that run through all or most of the pertinent data or one in the minority that carries heavy emotional or factual impact.

My discussion will now focus on the analysis of data collected with the different tools and strategies via: research project given to the learners I refer to as "open investigation", questionnaire and worksheets, audio-visual workshop observation and finally interviews.

4.5 Prior knowledge elicitation and analysis

4.5.1.1 The "open" investigation

The open investigation took place between the 31st of January and the 17th of February 2003 (with their consent). The idea behind the open investigation was to create the opportunity and an appropriate environment for the learners to find out things for themselves.

4.5.1.2 Results from the open investigation

Learners were requested to visit their communities, surroundings or neighbourhood and identify natural phenomena (NP), environmental occurrences (EO) and human processes (HP), which they could argue as oxidation and reduction (redox) reactions.

I used the following codes: learner one (L1), learner two (L2), learner three (L3), and so forth up to learner twenty (L20). I want to mention that the individual learner and I knew the identity and was not disclosed to other learners. In analysing the data, I read through the responses carefully and highlighted the patterns I identified, then coded the pattern as depicted below. The codes used are the same as those mentioned earlier as natural phenomena (**NP**) environmental occurrences (**EO**) and human processes (**HP**). However, those responses not linked to any of the above, which were considered to be concerned with a redox process were coded (**RP**) whilst the discussions that are book-copied are coded **BC**. None of the responses are presented in edited form. The bold areas in brackets represent my analysis as I proceed with the responses.

4.5.1.3 Examples of learners' reports/investigation

L9 – "Reduction is to make something small (**language interpretation**). For example, rust (***EO***) is a chemical substance called iron oxide. It forms a reddish-brown coating whenever iron or steel come into contact with air and water (linking to redox). As more and more rust forms, the metal is eventually completely worn out (**explains the language interpretation**). Green plants and small organisms that live in the sea produce oxygen and the process of giving away is called oxidation (***NP*** – however explanation is for reduction – **misconception here**). In factorys, (sp) [sic] there are chimnies (sp) [sic] to put unwanted gases and oxygen stays to keep the fire burning by that we are reducing the gas (***HP***)". L9 caption her project as "Science".

The title of L10's research project is "Air Pollution". This is what she had to say: "In my understanding of redox, the word that comes to mind is air pollution because air is part of nature. Air pollution is caused by air that comes to factories, and it is called carbon monoxide. Air pollution damages ozone (***EO***) layer (*redox*), which covers the sun. Air pollution is also caused when sulphur reacts with oxygen (oxidation) and forms sulphur dioxide (***EO***). Sulphur dioxide reacts with water it forms sulphurous acid causes acid rain (*redox*)".

L18 – "I think the pollution is the other example of oxidation and reduction reactions. During the burning of coal and oil, air pollution substances such as dust, smoke, ashes, carbon monoxide, sulphur dioxide and bits of lead and other heavy metals are released when wind and rain do not disperse the substances (**difficulty in expressing one self due to language problem**). The main pollutant is nitric oxide produce by motor vehicles with internal combustion engines and emitted as exhaust (**misconception**). In the air nitric oxide reacts with oxygen (***EO***) and nitrogen dioxide (*redox*) can react with hydrocarbons (***EO***). The other thing is that acid rain is formed when carbon reacts freely with oxygen in the air".

L15 approached her research project titled "Air pollution and Temperature change", just as L18. However, she mentioned a few more touchy issues, such as:

"Atmospheric gases such as oxygen is required for respiration (***NP***), carbon dioxide (***NP***), photosynthesis (***NP***) and nitrogen for protenthesis (sp) [sic]" (***NP*** **though not familiar with the term).**

L7 – "The fact that our parents work in order to earn a living releases gases that pollute the air we breathe. The cars we drive also play a role in air pollution, the perfumes we wear also are a danger to us. The paraffin we use to cook is also one of the elements that play a role in air pollution. The above sources of air pollution cause a decrease in the oxygen content in the atmosphere (***EO***)".

L4, and many others, I believe, consulted a textbook (same book probably) and presented exactly what is written in the textbook. I choose L4's report to represent all that fall in that category as an illustration: "In the discussion of electrolysis of copper (ll) chloride solution, the formation of chlorine at the anode (positive electrode) was explained by means of the equation:

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

We then said that the loss of electron is called oxidation and electron gain is reduction (***BC***). Oxidation- reduction is electron transfer"...(***BC***).

Learners L11 and L19 presented a report which was a surprise to me. Below is an extract of their report:

L11 gave the title of her report as "Deduction and Oxidation". "Chemical bond is the force of attraction that holds atoms together. Each bond represents a certain amount of chemical energy"............(***BC*** **and misinterpreted the question**).

L19 – "Oxidation is the number indicating the number of electrons actually or naturally lost or gained by an atom of an element when chemically combined. Charge, another property of subatomic particles is electric charge (**change in perspective**). Because the charge of a subatomic particle is always a multiple of a certain value it is said to be "quantized". The energy of a light beam of a definite frequency, such as red light is also quantized. A particle of light of a definite frequency is called a photon or a light quantum (**another change in perspective**). Quantum is a discrete quantity of energy" ..(***BC***).

4.5.2 The Questionnaire: Further elicitation of prior knowledge – (Appendix A)

To further investigate the participants' prior knowledge and to probe deeper into the report on their research project, I administered a questionnaire, which was completed by the participants. All the questionnaires distributed to the learners were returned, though only seven of them (participants) responded to all the questions, and the others responded partly. An interview was organised as a follow-up on the questionnaire. The questionnaire was in two parts. One part seeks to delve into the participants' general social background and the second part investigates prior knowledge related to redox reactions [see Appendix A].

4.5.2.1 Part A of the questionnaire

I wanted to explore the learners' social and academic background. Some of the questions addressed included age, gender, location of residence, name of school and present grade, amongst others. However, a few of the questions are open-ended, examples of some of which I present below, together with sample responses. This was to guide me as to how I should frame the subsequent questionnaires, prepare the teaching and learning unit, as well as the interview questions.

1. ***Mention three of your most favourite subjects in order of preference.***

All the learners mentioned mathematics as their most favourite subject, whilst physical science was their second or third preference.
However, it would have been very helpful to follow up on this question to enquire their reason for the preference of maths over science

2. ***How do you feel about science as a subject?***

Many of the learners claim to **"feel good, great and excited** (using the learners own words) doing science especially when it is time for science lessons". Some of the reasons given were: science is full of practical activities, it is not the usual "sit and receive" mode of learning, but related to real life situations and full of fun. Presented below are a few of the participants' responses. The code used follows the similar format as that used in the open investigation. The samples are not edited.

L20: I feel great when it is science period because it is not difficult to apply something you have learned in class at home (**language difficulty**).

L1: I feel very proud because it makes me to learn everything about nature (**language problem**). It helps me to gain more knowledge about it (nature).

L12: I feel like a scientist, it makes me proud of myself and when I learn it, it makes me more interesting (**expression difficulty**).

L17: Science is quite an interesting subject because you don't just learn about things, you experiment a lot of these things. It gives more knowledge.

L9: I like it very much because it is more related to our everyday life and environment. It is about the things we do and see everyday.

L8: Science is exploring and exploring is fun. I feel good because science is about all living and non-living things of which I am one of them.

L3: Science is nice because it opened our minds and to be creative, co-operative with people and not thinking that science is just a subject it is day-to-day living.

L15: This learner expressed an opinion quite different from all the others, which I feel needs to be mentioned: "I feel terrible when the teacher taught about science because I don't understand" (Further probing revealed that she had been forced by her parents to take science as one of her subjects).

3. ***Describe your most interesting science topic in your previous grade and what made you to enjoy this topic.***

Most of the learners describe pollution in general (while a few were specific on air pollution) as the topic they found most interesting. Some of the explanations given were as follows:

- It thought [*sic*] me not to throw litter about especially into running or stagnant water.
- It thought [*sic*] me how air pollution can damage their lives (health) and bodies.
- It helped me to understand the cause and effects of acid rain on the environment.

A few of them, however mentioned atoms, chemical bonding, waves, electricity, pressure in liquids and acids and bases. I did not probe further for the reasons for their choice.

4.5.2.2 Part B of the questionnaire

The aim of this section was to evoke the learners' prior knowledge and determine their level of understanding of some previous learning experiences and how they could be used within the framework of the research topic. The questions that make up this part are outlined below, with sample responses from the learners. The questions focused on combustion reactions, photosynthesis, respiration, metabolism, through to oxidation and reduction reactions (the area under investigation).

1. ***Combustion is one of the topics you studied in your previous grade.***
    - How do you feel about this topic in general?
    - What have you learnt from this topic?
    - Describe briefly what combustion is all about?
    - What are the essential components of combustion?

The learners response to the first bullet was either they feel "good", "great" or "challenged". On the second issue, varied responses were given, which include the following (unedited).

- "That the oxygen plays a big role in burning things" (**only associate combustion to burning**).
- "I have learnt (L15) a lot because we are told about the substances that burn in oxygen" (**focus is on burning**).
- "I've (L2) learnt many things like chemical reactions. It thought me that magnesium and magnesium will not react" (**true but could not explain why**).
- "Chemical reactions are accompanied by evolution of heat or absorption of heat and when heat is given out the products and the reacting substances may be raised to temperature at which they emit light" (**fragmented knowledge**).
- "As combustion is part of nature (L16), so it taught me how to protect nature. Man always destroys nature" (**expression difficulty due language deficiency**).
- "I have (L8) learnt that combustion is a rapid chemical reaction accompanied by the release of a noticeable amount of energy in the form of heat and light" (**demonstrated some amount of understanding**).

- "I've learnt that combustion is dangerous (L20). It can cause air pollution" (**associate combustion to burning**).

- "I have learnt different things caused by combustion (**language difficulty**). I learnt about how sodium combines with oxygen, sulphur reacts with oxygen and calcium burns in oxygen" (**organised prior knowledge**).

The reflection portrayed on the third issue is that combustion is all about burning of substances in air (**mental image of practical activities**). Excerpts of the responses are presented below unedited:

L3: "It is about the burning of substances and heat forms".

L7: "Its about burning of substances. Its distruction by fire, development of light and heat going with chemical combination".

L13: "It is about reacting of substances carried out under different conditions i.e. A substance like sulphur is burned in the air or candles. Burning sulphur/magnesium produces their oxides".

L18: It is the process of burning, chemical process accompanied by heat in which substances combine in the air".

L15: "Combustion is a burning process".

Four of them however, generalised their explanation on the reaction (combustion) of substances with oxygen.

L5: "It is about a chemical combination of substances with oxygen and energy being released in the process".

L1: "Burning of substances or chemical reaction of substances and oxygen".

L19: "It's involving a chemical combination of substances with oxygen

L17: "Its about the elements that react with oxygen. This process we call it combustion.

Eg: Carbon + Oxygen = Carbon dioxide".

Finally, all the respondents to the above questions mentioned air (oxygen was mentioned by a few) and carbon dioxide (one respondent mentioned carbon monoxide as an additional component) as the essential components.

L17: "Carbon dioxide as a component. Oxygen is also a component. Example, candle burns in air or oxygen and carbon dioxide is formed according to the equation: $C + O_2 \rightarrow CO_2$

L8: "Oxygen is very important, carbon dioxide and sometimes carbon monoxide is produced. Then energy is released".

L7: "Energy, air and light".

L9: "water vapour, oxygen and carbon dioxide".

Two of the learners mentioned that they felt bad about the topic because it was too difficult for them to comprehend.

L14: "this topic was too difficult and I did not understand it".

L6: "I did not like this topic".

However, L11 and L4 did not respond to the questions at all, giving the reason that they were not taught this particular topic in the previous grade (**revealed during a follow up interview**). If they were not taught this topic, then their prior knowledge may have been deficient and they may have experienced some difficulties when the research topic was introduced.

2. ***In your biology lessons, some of the important topics you studied were photosynthesis, respiration and metabolism. Kindly express your understanding of these topics.***

The learners demonstrated familiarity and understanding of photosynthesis and respiration (basic principles) but not metabolism (refer to 2.1 and 2.2). Many of the learners described photosynthesis as the process whereby green plants make their food by the use of energy from the sun and carbon dioxide from the air and produce oxygen (**basic explanation**).

- "It the process where plants with green leaf use carbon dioxide in the air to make food".
- "Green plants make starch from the energy of the sun, carbon dioxide from the air and water and give away oxygen".
- "It is the process by which green plants manufacture starch by making use of sun energy and carbon dioxide and release oxygen".

Others describe it as a method of nutrition in chlorophyll-containing plants, which uses radiant energy and also as a process of producing organic food, mainly carbohydrates, releasing energy and oxygen in the process (refer to 2.1 and 2.2).

One of the learners described photosynthesis as a complex biochemical process, which occurs in green plants. "It is also a process whereby green plants manufacture sugar and starch from carbon dioxide and water using the energy of the sun" (**a more complex description**).

2.1. On respiration, the learners overwhelming responses were:

- "It is a chemical process of taking in (absorption) of oxygen for the oxidation (breaking down) of substances (organic in particular glucose) with the gradual release of energy" (**demonstrates understanding with a confident explanation**).
- "It is the process by which an organism supplies its cells with oxygen needed and removes carbon dioxide formed in the energy producing reaction" (**understanding depicted in description**).
- "Respiration is the process whereby we breathe in oxygen, which means that oxygen is added, and we breathe out carbon dioxide, which means that it is the removal of carbon dioxide" (**basic explanation**).

2.2 In an attempt to explain metabolism, a few of the learners had this to say:

- "Metabolism refers to all the complex biochemical processes, which take place in living systems. The metabolic pathways in living organisms are closely associated with the availability of energy in biochemical reactions or activities. Most of the reactions are dependent on enzymatic reactions. That is the enzymes and coenzymes, which catalyse the biochemical processes" (**a conversation with the participant revealed that the respondent does understand the topic well**).
- "Metabolism is a chemical change in living cells by which energy is provided and new materials assimilated" (**demonstrated understanding during a conversation**)
- "It is the process by which food is built up in living materials or used to supply energy in a living organism" (**little understanding demonstrated during a conversation**).
- "It is about all the chemical changes (construction and deconstruction) occurring in living organisms. It includes nutrition, energy production and the synthesis of more protoplasm" (**showed understanding during conversation**).

However, the majority could not respond to this particular sub-question, with the explanation that they did not understand the topic when it was taught.

3. ***What role does oxygen play in all the processes described above (respiration, photosynthesis and metabolism)?***

This question seems to refer to an area of their knowledge, which might be generally sketchy since most of the learners could not respond to it. A few however, mentioned the role of oxygen in photosynthesis and respiration as defined in the textbook (**mental image of textbook material**).

- "Oxygen is taken in during respiration and given off in photosynthesis".
- "Mammals take in oxygen and plants give out oxygen".

With metabolism, the learners could not make any connection of oxygen with it (**inability to link oxygen to these three processes though textbooks do connect this**). Furthermore, one learner mentioned that oxygen supports all three processes (**but could not explain during a conversation**).

4. Briefly discuss oxidation and reduction reactions.

Most of the participants described oxidation as the addition of oxygen to a substance and reduction as the removal of oxygen from a substance (**oxygen model**). One learner further explained that "the terms oxidation and reduction were limited to reactions where elements combine with oxygen or where oxygen is removed from a compound" (**oxygen model**). A few of the learners explained oxidation as the loss of electron(s) by a substance, (an atom or a molecule) and reduction to be the gain of electron(s) by a substance (an atom or a molecule}.

- "Oxidation means when a substance reacts with oxygen (addition of oxygen) and reduction when is when oxygen is given away (removal of oxygen)".
- "Addition of oxygen is oxidation and taking away of oxygen is reduction".
- "Substances that receive oxygen are oxidised and those that loose oxygen are reduced".
- "The chemical combination of substances with oxygen to form the oxide is oxidation, whilst the removal of oxygen is reduction".
- Oxidation is the loss of electron(s) and reduction is the gain of electron(s) by a substance".

5. How would you describe combustion, respiration, photosynthesis and metabolism in terms of oxidation and reduction reactions?

Only five of the learners responded to this question. Some of the responses are (unedited):

- Oxygen is an important part of all, either as a reactant or as a product.
- The processes can be classified as redox reactions since in all cases, oxygen is added or removed. Oxidation-reduction reactions are regarded as two complementary processes similar to the biochemical processes respiration, photosynthesis and metabolism requiring or liberating energy in living organisms (**well explained**).

- All the reactions in the above processes involve the loss or the gain of electron(s) (**the respondent could not substantiate this statement when interviewed**).

The majority of the learners could not respond to the question, claiming that they did not know of, or how to describe combustion, respiration, photosynthesis and metabolism in terms of oxidation and reduction reactions.

4.5.3 Practical activity as a means of eliciting prior knowledge

The focus my of the prior knowledge elicitation practical activities were:

- Combustion reaction as a redox process (oxygen model).
- Displacement reaction as a redox process (electron-transfer model).

The questions that constitute the practical activities 1 and 2 were:

1. ***Combustion Reaction –reaction of oxygen with substances such as carbon, sulphur and magnesium (see Appendix B).***
2. ***Reactions of some metals with solutions of other metal salts (see Appendix B).***

However, before embarking on the practical activities, pre-practical discussions and evidence of preparation of the learners was conducted. The pre-practical discussions were mainly to clarify any misunderstandings that may have been prevalent, to consolidate ideas, to help to remove any ambiguity that might be in the instructions and set the scene for the practical (Rollnick *et. al.* 2001: 1060). It became evident that the discussions were meaningful, as they gave the participants 'scaffolding' on which to construct the activities (experiments).

4.5.4 Results of the practical activities

Evidence of preparation: The pre-practical discussion held before the activities (1 & 2) revealed that most of the learners were well prepared, whilst others were less so. This deduction came from the observations made as summarised in Table 4.1.

Table 4. 1: Preparedness of participants

Context	*well prepared learners*	*less prepared learners*
Approach to practical activities	- started almost immediately - well composed, organised and worked quiet - followed instruction with ease	- spent time repeatedly reading the through instructions over and over - difficulty in following instructions
Questioning by learners'	- asked questions to confirm correctness of reasoning -asked questions on other topics related to the activity	- asked questions with the intention of getting the answers without reasoning - conferred with friends to confirm if (s)he was doing the correct thing
Completion of instruction 20 of activity 1 (appendix 2) and instruction 3 of activity 2 (appendix 2)	- presented a systematic observation with conclusion and completed table on time	- difficulty in recording observations and in most cases could not draw conclusions from observations
Response to worksheets	- completed most questions on the worksheets demonstrating a good understanding of the activities.	- left most of the questions in the worksheets unanswered demonstrating very limited understanding of the activities.

However, one issue that featured in the responses of both groups (well and less prepared) of the learners was that they could not associate activity 1 (Appendix B) with the oxygen model and activity 2 (Appendix B) with an electron-transfer model of redox reactions.

Procedural skills: Initially most participants had difficulty in handling the equipment but became conversant with its use and worked with ease. Though the instructions were very clear, direct and easily followed by the 'well prepared' learners, the 'less prepared' learners had problems in reasoning out the demands of the instructions, with incorrect reporting of significant observations. One observation made was the readiness of the 'well prepared' learners to share knowledge with the 'less prepared' learners. This showed me that preparation of the learners before any activity needs to be emphasised.

Conceptual manifestations: Many of the learners had conceptual problems on redox reactions and requested assistance. Several instances of issues related to learners' conceptual understanding of redox reactions were identified during the practical observation and from their responses to questions on the worksheet involving redox reactions. One respondent could not describe whether burning carbon in oxygen to form carbon dioxide is a redox process or not. Similarly a few of the respondents could not deduce that if magnesium displaces copper ions from copper sulphate solution to form the copper metal, it is a redox reaction. As rightly put by Rollnick *et al*., (2001: 1063) "Understanding conceptual issues are vital if learners are to make sense of practical activities". I concur with this statement since my own experience has shown that making the correct observation and deduction depends largely on the understanding of the relevant concepts.

4.5.5 Emerging Themes – Pre-intervention stage

The outlined themes were the general observations made during the pre-intervention stage of the research process.

Theme 1: *Language limitation*. The level of learners' English literacy had an adverse effect on their response to questions. Majority of them had some sort of idea to express but could not do so due to this problem (**effect of mother tongue as medium of instruction in the lower grades**).

Theme 2: *Interpretation of questions*. The learners' rudimentary grasps of the English language led them to misinterpret some of the questions and to constantly request help (**inadequate English vocabulary**).

Theme 3: *Conceptual issue*. Observations made from the learners' responses demonstrated a lack of integration of scientific concepts. These were treated in isolation and not related to other units, even to real life issues (**a problem of compartmentalisation of knowledge**).

Theme 4: *Linking classroom teaching to real life situations and vice versa.* Our teaching and learning is dominated by the emphasis placed on textbook knowledge. This is evident in the **'textbook mental image'** produced by the learners.

Theme 5: *Fragmented prior knowledge.* Lack of organised prior knowledge was demonstrated in the responses of the learners (**topics are taught as independent units**).

Theme 6: *Inadequate handling of equipment.* Practical activities performed in science are characterised by teacher-demonstration, thus denying learners the opportunity to handle equipment. Unavailability of resources creates an attitude of preservation of the limited resources available, to the detriment of acquisition of experience and knowledge by our learners.

4.6 Intervention stage analysis –Probing and developing conceptual understanding of Redox processes and reactions.

After collecting, collating and analysing the data on the prior knowledge elicitation stage of the research project, as demonstrated earlier, it became necessary to intervene and address the issues that emerged. The intervention stage was characterised by an investigative teaching and learning unit, with practical activities accompanied by worksheets. It is my opinion that teaching and learning of scientific knowledge should be evidence-related, which emphasises the need for adequate practical activities and worksheets. However, identification of key concepts to be developed is pivotal.

The three tools (investigative teaching and learning unit, practical activities and worksheets) were employed to develop the four theories of redox reactions. The concepts explored were:

- Addition and removal of oxygen as redox reactions, which I refer to as the 'oxygen model' or the 'traditional concept'.
- Removal and addition of hydrogen as a redox reaction, referred to as the 'hydrogen model'
- Electron transfer theory and
- Oxidation number model.

The basic definitions of these models are outlined in Table 4.2.

Table 4. 2: Summary of redox concepts

MODEL	*BASIC DEFINITION*	
	OXIDATION	*REDUCTION*
❖ *Oxygen model*	*Gain of oxygen*	*Loss of oxygen*
❖ *Hydrogen model*	*Loss of hydrogen*	*Gain of hydrogen*
❖ *Electron transfer*	*Loss of electron*	*Gain of electron*
❖ *Oxidation number*	*Increase in oxidation number*	*Decrease in oxidation number*

4.6.1. Investigative teaching and learning unit

Before embarking on the classroom (theoretical) teaching and learning program, the learners and I went to the community (township) to identify activities that could constitute redox processes, (similar to that which the participants did in their open investigation) after introducing the participants to the unit under investigation. They were split into groups of four with a group leader and were to look out for:

- ***Roofing materials, (types, colour and change in appearance) comparing two or more similar types.***
- ***Metal fencing, comparing two or more of similar types for any change /difference in appearance.***

Most of the groups reported that the roofing materials they observed included 'tiles' with clay as the raw manufacturing material, 'asbestos' and 'iron sheets' which are commonly referred to as 'izinc' and often misconstrued as the metal, zinc (prior knowledge can create misconception). They noticed that the tiles and asbestos roofs had not changed in appearance and all looked virtually the same. However, a comparison made between the unpainted and ungalvanized iron sheets revealed a difference in appearance. They claimed the old iron sheets looked dull and brownish, indicating that a reaction had taken place. One group described the brown coating of the iron sheet and fencing as rust a view supported by the other groups. Most groups expressed concern that, with the rust formation, the metal wire that constitutes the fencing had reduced in size and gradually became very thin and broke easily. Three of the groups successfully explained the chemistry of the rusting process and associated it with redox reactions. Members of the three groups that demonstrated a good understanding helped the two groups that could not explain the process involved. A follow up discussion of the experience aroused the interest of all involved in the project, resulting in the learners calling for more learning concerning the unit investigated.

4.6.2. Teaching and Learning unit [Appendix C]

Drawing from the learners' responses and considering the interest demonstrated, the implementation of a teaching and learning unit became inevitable (see Appendix C). The teaching and learning unit included two practical activities with worksheets.

Intervention Practical Activities [Appendix D]

- Activity 1: ***Investigating the reducing ability of a few metals in terms of metal displacement reaction and arranging the metals in order of a reactivity series.***
- Activity 2: ***The oxidation property of the Halogens. This is also a displacement reaction.***

Procedural argument: The procedural argument points to the ability of the groups to prepare their own solutions for the experiments and to be guided by instructions to develop practical capability of laboratory technique and methods that are essential in obtaining reliable and accurate information. At this stage, the groups applied the experience they had gained (as individuals) in the pre-intervention stage, producing evidence of great improvement in their procedural approach and handling of equipment. They provided informed, credible and viable information (required by Tables 3 and 4, Activities 1 and 2 of Appendix D).

Of the five groups, only one group demonstrated a little difficulty in preparing the solutions as required. They solved their problem by observing what their fellow groups were doing, and then doing the same (I call this the "slow learning" group). They did not seem to have direction of their own. Subsequently, they received help from another group. One member of the slow group asked the question "Why is it necessary for us to prepare our own solutions"?

One group responded by saying that "it was to remind them of the unit on solutions they had studied". I then emphasised the importance of integrating topics.

Observational argument: I believe that a reliable and viable practical report is established on the basis of a developed set of observational skills. I will argue further, that a developed observational skill does not develop by doing one or two practical activities. Rather, it is achieved by regular, self-performed experiments under the guidance of a facilitator.

All five groups demonstrated sound observational skills. This was evident in the post practical discussion of Activity 1, Table 3 and Activity 2, Tables 4 and 5 (of Appendix D), although two of the groups had difficulties with colour identification (Table 5 – Appendix D). I believe that a demonstration of adequate observational skill does not only stress the content of the unit investigated, but also encourages analytical thinking that eventually contributes to understanding that content.

I will now discuss the outcomes of the practical activities performed by the learners.

Activity 1 [Appendix D]

Table 3 (Appendix D): All the groups identified and described the precipitates formed wherever applicable and mentioned no precipitate/no visible reaction where nothing was observed. They successfully identified the reduced and oxidised substances. This was evident in the completed Table 3 (Appendix D) when groups began to ask questions instead of waiting to be asked by the researcher during plenary discussion of the experimental report. Learners asked a great variety of questions to which other learners often provided the answers. For example, during the plenary discussion of the practical activity, a participant asked a question about the bubbles observed when an iron nail was immersed in an iron (ii) sulphate solution. An excerpt of the discussion is presented below:

Excerpt 1:- describes the conversation that ensued during the plenary discussion.

Gp A : There is air in the iron sulphate solution.

L_1 : Where does it come from?

Gp A : Air dissolves in solutions

Gp C : No it was not the dissolved air that came out as bubbles rather, hydrogen gas was produced.

Class : (A surprised expression, then loud laughter)

L_2 : Can you explain?

Gp D : Do you remember the experiments we performed in grade 9 concerning the reactions of acid with certain metals such as zinc, iron and magnesium?

L_2 : Yes, but I did not understand that lesson and even now.

L_1 : Sir, is what group C said correct?

R : Yes

L_3 : Please can you explain that for us to understand?

R : Okay, but first can any group attempt to explain this? Group C

Gp C : Yes sir, certain metals when immersed in an acid solution produce hydrogen gas. So we think iron sulphate solution is an acid solution.

R : Good thinking there. In fact, iron sulphate is not an acid. However, it has traces of acidic properties (same with zinc sulphate) therefore when the iron nail was dipped into the iron sulphate solution; one observes effervescence, indicating the production of hydrogen gas due to hydrolysis of iron sulphate solution. This was not a displacement reaction as expected.

[L = learner, Gp = group and R = researcher]

The discussion furthered the learners' interest in the unit of analysis and more so, their application of prior knowledge with effort to integrate topics in science.

Although learners in the groups indicated an understanding of the activity performed, it was necessary for me to find out how profound the learners' understanding of the concepts of oxidation and reduction was and this was carried out with the problem below.

The groups were asked to:

- Represent the reactions (that occurred at the various stages of the experiment) by a half-reaction and then a net redox reaction
- Arrange the metals in a decreasing order of reactivity (with the most reactive first, followed by the next to the least reactive metal).

Of the five groups responding to the first problem, three groups correctly presented the half-reactions as well as the net redox reaction equations, demonstrating an understanding by balancing electrons correctly. During a presentation of their equations, it came to light that two of the groups who responded correctly to the problem, applied the electron-transfer model while the other group applied the oxidation number model. One of the two remaining groups presented equations for the half-reactions but could not proceed to present the overall redox equation for the reaction with the reason that they "have difficulty in the balancing the electrons (further explanation required). The remaining group, on the other hand, was only seeking help from me, instead of challenging or bouncing their ideas off each other in the form of questions or guidelines. They could not apply what was discussed during the teaching and learning session effectively and were solely dependent on the other groups and myself for answers. Their attitude depicted a limited conceptual understanding of the unit of analysis. However, this group was able to write the general equations for the reactions that occurred. Example:

$$FeSO_{4(aq)} + Zn_{(s)} \rightarrow ZnSO_{4(aq)} + Fe_{(s)}$$

In responding to the issue of arranging the metals in order of reactivity with the most reactive on top followed by the next to the least reactive, four groups presented the correct order of reactivity of the metals, whilst one group presented their report in the reverse order (**mis-interpretation of question**). All the learners declared an understanding of the activity series after the discussion. One learner mentioned that she wished that in the future, they would be allowed to perform experiments in groups (**group work essential**) instead of the teacher (facilitator) always demonstrating experiments (**approach to teaching practical activities**).

Activity 2 [Appendix D]

In this activity, the learners (groups) were required to investigate the oxidation of one halogen by another. Two tables were provided (mentioned earlier) for the groups (learners) to complete (Appendix D). One was for recording observations and the other for drawing conclusions.

Almost all the groups appeared confident, assertive and presented orderly and correct observations. Clarification questions voiced by the groups during the experiment included those asking, 'Is this purple or navy blue that we observe'? However, the majority of their clarification questions were not hesitant or lacking in confidence, but were seeking confirmation. A few, including myself, battled with colour identification, which called for the use of a colour chart. For example, in excerpt 2 below, a learner in one group demonstrated how uncertain he was with the colour observed when bromine water was added to potassium iodide solution:

Excerpt 2:

P1 :	Potassium iodide solution originally colourless.
Plenary:	Yes.
P1 :	Bromine water is brown.
Plenary:	Yes.
P2 :	But when we added the bromine water to the potassium iodide solution, the potassium iodide solution turned red.
P1 :	No, we cannot describe this colour as red.
P2 :	What colour is this?
P1 :	It is pink.

The colour chart could not help very much, since the colour observed was between red and pink, which does not conform to the theoretical colour prediction.

To challenge the learners conceptual understanding of the experiment and hence oxidation and reduction reactions, the question below was posed by the researcher.

Explain why these colour changes occur and give the equation for the half-reaction as well as the net redox reaction equation in each case.

Almost all the groups explained the change in colour, wrote the equations for the half-reactions and the net redox reactions equations correctly. However, one group, who seemed to lack confidence in writing the net redox reaction equation, was helped by a member from another group. Their overall report depicted quite a good conceptual understanding of oxidation and reduction reactions. The predominant models employed by the groups were the electron transfer and the oxidation number concepts. The initial difficulty the learners had in recognising redox reactions seemed to have been overcome (**understanding seemed to have been achieved**). The themes that emerged from the teaching and learning session are my next issue to discuss.

4.6.3 Emerging themes:

Theme 7: *Building of confidence* was demonstrated during plenary discussions, debates and conversations. The excerpts presented, depict the learners' level of confidence developed through the intervention session.

Theme 8: *Designing of the 'teaching and learning unit' and 'teaching experiments'* facilitated not only teacher-learner interaction, but also learner-learner interaction. As all the learners followed the same sequence of steps, it was possible for them to intervene in the discussion of findings whenever they felt the need to do so.

Theme 9: *Flexibility of the 'teaching experiments'* allowed learners to engage in learner-learner interaction by the formation of small groups and to come up with a joint response.

Theme 10: *Clarification and confirmation questioning* during the teaching and learning interaction, discussions, debates, conversations and reports provided evidence of the learners' conceptual understanding of oxidation and reduction reactions.

4.7 Post-intervention analysis – Consolidation of intervention

To consolidate what had been achieved the research these tools were employed:

- Audio-visual observation workshop and an
- Interview

4.7.1 Audio-visual observation workshop – video recorded workshop

The workshop and recording took place on Saturday the 24th of September 2003 at my school, which gave all involved in the research, ample time to go through the process without any time limitation. The learners worked in their research groups and selected their own 'presenter'. I believe that working in groups enables the learners to share their experiences, ideas, knowledge and perceptions. Furthermore, all the learners actively participated in their group discussions and expressed their interest in the process.

4.7.1.1 Audio-visual observation workshop data analysis [Appendix E]

The main issue discussed was:

- ***Evoking the participants' prior knowledge and confirming their understanding of redox reactions through 'word-association exercise' –WAE.***

The learners were required to interact with and brainstorm one another in their groups and then present their finding to the plenary. The topic was; terminologies of oxidation, reduction and redox. With redox the learners were encouraged to use practical/real life situations, natural phenomena, environmental issues and biological activities to demonstrate their understanding.

Learner's responses

I present the words that learners associate with the concepts; oxidation, reduction and redox. The presenters made all the necessary effort to explain each term or word(s):

Words associated with oxidation

- * addition of oxygen (oxygen model)
- * removal of hydrogen (hydrogen model)
- * loss of electron(s) (electron transfer model)
- * increase in oxidation number (oxidation number model)
- * reducing agent
- oxidised substance
- positive ion
- less negative ion
- change in colour of solution
- oxidation half reaction
- oxidation half cell

Words associated with reduction

- * addition of hydrogen
- * removal of oxygen
- * gain of electron(s)

- * decrease in oxidation number
- * oxidizing agent
- negative ion
- less positive ion
- reduced substance
- opposite of oxidation
- reduction half reaction
- reduction half cell

Words associated with redox

- * oxidation and reduction
- * simultaneous reaction
- * net redox reaction
- * photosynthesis
- * combustion of fuels
- * rusting/corrosion of metals
- * respiration
- oxidant and reductant
- loss and gain of electron(s).

Words marked with asterisks are those that appeared in the reports of all the groups whilst those unmarked appeared in some groups only.

One presenter explained why they considered photosynthesis to be a redox process as (unedited):

Pr 3: "During photosynthesis, the green plant gains energy. When the chlorophyll in the plant absorb radiant energy from the sun, the water in the chlorophyll split up into hydrogen and oxygen. The hydrogen goes into the NDP and the oxygen goes into the atmosphere. We can then say that there is removal of oxygen, which is reduction and again removal of hydrogen, which is oxidation. This therefore means that photosynthesis is a redox reaction" **(demonstrates understanding of the concepts of redox in a biological system).**

The transcript picked up these discussions when the other learners, which I present below as excerpts, challenged the presenters of the individual groups:

Excerpt 3: This is a debate between a learner audience and the fourth presenter for group D.

L : You have explained very well to my understanding the concept of oxidation and reduction. Now under oxidation, what is the chemical reaction of addition of oxygen and under reduction, what is the chemical reaction of the removal of oxygen? (requested a reaction illustrating the addition and removal of oxygen as a redox principle)

Pr4 : (long pause…scratch the head…fell into a deep thinking and put up a smile then looked at his group and suddenly a member of the group [PrD] came to the front to explain).

PrD : Let us consider the reaction between carbon and oxygen. Carbon reacts with to form carbon dioxide.

$$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$$

Here, oxygen has been added to carbon - oxidation

Again, when magnesium reacts with steam ($H_2O_{(g)}$) the magnesium removes oxygen from the steam forming magnesium oxide and hydrogen gas evolved.

$$Mg_{(s)} + H_2O_{(g)} \rightarrow MgO_{(s)} + H_{2(g)} \quad \text{- (redox)}$$

The steam has been reduced to hydrogen by the removal of oxygen by magnesium (**demonstration of conceptual understanding of redox process**).

L : Thanks, I am satisfied.

Excerpt 4: This excerpt presents the challenge posed by a learner to the fifth presenter, representing group E.

L : When you put iron nail in water, bubbles are produced signifying that a gas is being released. Is it oxygen gas? Can this gas be collected? If so how?

Pr5 : I don't think that the bubbles you observed was oxygen gas, rather it could be hydrogen.

L : Why?

Pr5 : Pause…Sheeee…well…okay…yes…I think the water may be slight acidic therefore, hydrogen gas might have been released (remember grade 9 experiment on reactions of acids with some metals). Secondly the iron nail rusts due to its reaction with oxygen and the water (**application of prior knowledge and integrating topics**).

L : How would you collect the gas?

L(E) : (A learner from group E responded). Yes... by connecting a delivery tube and collect over water (preparation of hydrogen and oxygen – grade 9 experiment).

R : A good demonstration of conceptual development. However, we need to do further investigation on this later.

I will shift my focus on the next tool (interview) used in collecting data.

4.7.2 Interview data and analysis [Appendix F]

The main interview took place on the 4th of October, 2003 in my school. I interviewed five of the six learners selected for the purpose. The sixth interviewee did not turn up for the interview. All efforts made to get her interviewed proved futile.

To minimise the effect of non-conducive psychological state (discomfort, fear, lack of confidence, and over anxiety of being interviewed) of the interviewees, three interview schedules were carried out using the same instruments and interviewer, thus making the learners familiar with the process. Secondly I (interviewer) assured the learners of confidentiality (ethical reasons). The learners were interviewed individually, as had been the practice in the pre-interviews. I believe this gave the learners courage to express themselves without reservation. The interview questions were classified in two sections: Section A seems to contain mostly 'settling down' questions and section B seems to be follow-up and probing of conceptual development regarding redox reactions. The questions were asked in English and the interviewees responded in English with sporadic pauses. I used the codes interviewer (I), learner 1...5 (L_1...L_5) for the respondents and R for popular responses.

4.7.2.1. Results from interview and analysis

Section A – Settling down questions and responses

*I : **Do you like this school and why?***

L_1 : I like it at the same time I don't like it. I like it because it is close to my home and secondly the teachers are hard working.
I don't like it because the building looks dilapidated and there are no laboratories for experiments.

L_2 : (long pause) Yes I like it is nearer my home.

L_3 : I like it, it is nearer my home so I can walk to school.

L_4 : Yes, I like it very much because the results are always excellent and the educators very friendly.

L_5 : (stalls for a while) Hmm…I don't know.

I : ***Explain to me a topic in chemistry or physics that you like most (not redox – because we had just completed discussions on redox reactions)***

Almost all the learners chose acids and bases as their favourite topic, providing about the same explanation. They said that the teacher used examples of home acids and natural occurring acids (vinegar, lemon and lime) to support his teaching (**importance of real-life illustrations in teaching scientific concepts**). Here are a few interesting responses:

L_2: "Some acids and bases are used regularly at home and others in the industry. For example, vinegar is a home acid whilst hydrochloric acid is mainly an industrial acid. Also, soap is a base used in homes and sodium hydroxide is used in the industry (sodium hydroxide used in the manufacture of some soaps)".

L_4: "Some acids, though harmful, are very useful. For example hydrochloric acid is very dangerous but at the same time human stomach lining secrets this acid to activate digestion (**integration of knowledge**). Also sulphuric acid is dangerous but it is used in car battery".

L_5: Long pause….murmured…."I just like the topic".

Section B – Follow up/Probing conceptual development of the investigated topic

I : ***Briefly describe your understanding of redox reactions.***

R : All the learners commented on the four models of redox reactions (mentioned in chapter two), illustrating each model with an example (**textbook mental image**). They went on to use real life situations to further their argument (**association of environmental activities to classroom knowledge on redox**).

One learner (L_2) said "I can relate respiration that happens in me as a redox reaction because I inhale oxygen and exhale carbon dioxide. Oxygen is added to my system and at the same time, oxygen is removed from my system, meaning that the process occurring is redox" (**human activity as a redox process: conceptual development demonstrated**).

I : ***We have performed an activity to determine the reactivity series. Apply your knowledge of the reactivity series to explain why certain metal salt solution cannot be stored in certain metal containers.***

R : The learners stated that considering the position of the metal in the series determines which one will react with which one. If the metal used as the container, happens to be more reactive than the metal of the salt solution, then there will be a reaction such that the container may not be suitable. However, if the reverse were to be the case, then that container could have been used.

L_3 further explained with an example that storing copper sulphate solution in an iron container is not appropriate because iron is more reactive than copper therefore, it will gradually displace copper ions from the solution depositing as copper metal while the container dissolves in the solution (**conceptual understanding demonstrated**).

I : ***Explain why roofing iron sheets are coated (galvanised) with zinc or painted?***

R : Some of the learners (L_2, L_3 and L_4) mentioned that the zinc used as the coating will undergo oxidation and the iron will be reduced because zinc is more reactive than iron therefore, iron will not rust (**conceptual understanding**). Two (L_5 and L_1) said zinc will be oxidised and iron reduced without any further explanation

I : ***Why was zinc metal attached to underground petrol storage tanks made of iron?***

R : Almost all the learners said the reason may be the same as the coating of iron sheet with zinc because the metals are the same as in the previous question.

I : ***Briefly comment on the approach I employed in delivering this topic (redox reactions)***

L1 : The practical activities and the visit to the community helped me to understand the topic and gave me more concrete evidence of the application of redox reactions. I hope this approach will be adopted in the teaching of the other topics. Last year for example, we did not do any practical activity on our own. The experiments were all teacher demonstrations (**lack of resources**).

L2 : My understanding of the concepts of redox reactions have been developed not only through a textbook approach but also through real-life situations and practical activities. The approach adopted has been helpful. I can confidently say that I can explain this topic to any one who may request that (**confident and proud**).

L3 : (shy to comment with lot of body movement).Hmm.... Sir, I like your teaching in general and more specially the way you went about teaching this topic.

L4 : You have tried. Well you are doing okay to make us understand whatever you teach. Sometimes you talk too fast (researchers' weakness) such that I cannot hear you properly. At times you talk slowly and use stories to illustrate your concepts which I feel great about because recalling those stories help me to understand better when I am on my own. Laugh...Sir, you are a good teacher (stall off the question to general comments).

L5 : Yoooh!!...Okay!!...Sir, I am happy with your approach (**lack confidence due to the medium of interview – English**).

I : Any comments you would like to make?

L1 : The systematic approach to the teaching and learning of this topic was very helpful in developing my understanding of redox reactions though it was time consuming.

L2 : Sir, I like your teaching in general. You have ways of making learners understand your teaching. But sir, please talk slowly for those with language difficulties to hear you properly.

L3 : No comment

L4 : Your approach to teaching science and mathematics has changed my negative attitude towards science and mathematics. I am gradually heading to the top in these subjects.

L5 : Okay!!...I like your teaching.

From the audio-visual observation workshop and the interview session some themes emerged, which form the focus of my next discussion

4.7.3. Emerging themes

Theme 11: *Motivation as a key issue* – the participation of the learners in discussion during the audio-visual observation workshop and the interview sessions demonstrates inspiration developed during the intervention stage of the research project.

Theme 12: *Imperious issue* – relaxed and conducive teaching and learning environment created gave all the learners equal opportunities (no learner domineering), candour was exhibited and unequivocalness applied.

Theme 13: *Positive reinforcement* demonstrated by all the learners in plenary discussions and interview session

The themes that emerged during the post-intervention stage of the research project (as outlined above) gave me the opportunity to conclude this chapter.

4.8. Conclusion

This chapter explicates the systematic process data collection, from its initial gathering, through its analysis accompanied by findings (emerging themes). The views and opinions expressed by the learners were also presented with my summary. Furthermore, from the discussions, conversations, debates and interviews it is clear that learners need absolute attention for conceptual development of redox reactions. It must also be borne in mind that it may be time-consuming to take learners through all the stages employed in this inquiry. However, I believe that a conceptual understanding of redox reactions (as demonstrated in this chapter) will contribute towards a better understanding of similar topics in other science disciplines. The findings made will be discussed in the next chapter.

CHAPTER 5

DISCUSSION OF FINDINGS, RECOMMENDATIONS AND CONCLUSION

> "Often you get the best insights by considering extremes – by thinking of the opposite of that with which you are directly concerned...when you try to contrast objects, you get a better grip on the materials and you can then sort out the dimensions in terms of which comparisons are made ... shuttling between attention to these dimensions and to the concrete types is very illuminating" (Wright Mills, 1978: 235)

5.1 Introduction to the chapter

The discussions and concomitant argument in this chapter pertains to the findings constructed and the emerging themes identified in the previous chapter. The interpretation of the findings was done against the background of the existing theoretical framework and the empirical evidence of the inquiry. Recommendations are suggested for future research, considering what I have interacted with, in literature and my findings. I believe this research will help other teachers to develop the skills needed for the learners to conceptualise the topic (redox reactions), which learners and educators consider being one of the most difficult topics.

5.2 Discussion of findings

The empirical findings of this study are presented combatively, subsequent to the themes that have been identified in each stage (section) of the previous chapter. In the discussion, I present my interpretation of the data obtained from the inquiry integrated with the emerging themes and reference to some relevant literature.

The main themes were:

- Theme 1: Organised prior knowledge
- Theme 2: Link between classroom learning and real-life situations
- Theme 3: Preparedness for teaching and learning
- Theme 4: Flexibility of the 'teaching Experiments'
- Theme 5: Positive reinforcement through discussions, debates, conversations, workshop and the interview
- Theme 6: Language proficiency (this is an emergent theme)

The study reveals four main findings as important in this inquiry:

- The first related to different forms of preparation embarked on in evoking and organising prior knowledge.
- The second was the application of several approaches to enhance learners' conceptual development of redox reactions.
- The third was the relevance of giving learners' an opportunity to demonstrate and share their conceptual understanding with one another through workshop and whole-class discussions (to stress the importance of consolidation) and
- the fourth was the appropriateness and implications of group work in promoting learners' conceptual understanding of redox reactions.

In the discussion of the findings I indicated the emergence of a theme by the inclusion of the theme in a bracket.

Two types of preparation (group and individual) were imposed on the learners in the study. Learners carried this out with various degrees of thoroughness (***Theme3: Preparedness for teaching and learning***) and it was thus possible to identify in the learners' participative behaviour, evidence of the consequence of little or no preparation. Learners who had adequately prepared for the various stages of the research project suffered less of the 'noise' described by Johnstone (1994 cited in Rollnick *et al.* 2001) and had a better chance of receiving the 'signal', to the 'message' of the research project (ibid). It was not clear what type of preparation was ideal; all types seem to have played an important role. What was clear, however, was that some learners and groups prepared thoroughly no matter how loaded they were with other academic commitments. The preparation required for the pre-intervention stage was the writing a review of redox reactions as studied in the previous grade and an overview of the combustion of certain substances in air. The learners were not given much help and often struggled to produce a write-up. However, the next stage (intervention) saw an improvement when guidance and assistance (pre-laboratory preparation) was given to the learners, resulting in their adequate interaction with the practical activities, though additional strategies were employed to help a few of the learners to contribute during the pre-laboratory discussions. I believe this was crucial if all learners were to participate actively in the research project and eventually the learning process to achieve conceptual understanding. The write-up was not marked neither was data gathered on the effectiveness of the preparations, but this area could be explored in future research.

The relevance of giving learners' an opportunity to demonstrate and share their conceptual understanding with one another through workshop and whole-class discussions (to stress the importance of consolidation) also came to light as an important exercise to enhance learners' conceptual understanding. Learners were more relaxed and asked questions during discussions, debates, conversations and the workshop. It revealed to me that a more conducive academic atmosphere is created when peers lead or present findings during plenary sessions.

The multiple approaches employed (contemporary and traditional) revealed learners' knowledge of the applications of redox reactions in real-life situations (***Theme 2: Link between classroom learning and real-life situations***). The more extended practical investigations with a focus on assembling persuasive evidence to support a conclusion, the better they substantiated the learners' conceptual development (***Theme 4: Flexibility of the teaching experiments***). These approaches, I believe provided appropriate contexts for learners to express their own views and opinions, and developed their understanding of key concepts of redox reactions, resulted in consolidation and reinforcement (***Theme 5: Positive reinforcement through discussions, debates, conversations, workshop and the interview***). Similarly, the processes helped learners to organise prior knowledge (***Theme 1: Organised prior knowledge***) for effective sorting and incorporation in new experience to develop greater comprehension (Wilson and Stensvold, 1988: 353).

This study also provided some revealing insights into the influences and impacts of group work. Ngcoza (1998: 29) contends that group work is not just placing learners into groups for the completion of a given task; learners should be able to learn from one another with tolerance. Having the learners work collaboratively in group discussions, workshop and conversation saw all the learners share their experience and knowledge with one another, thereby enhancing the construction of knowledge and conceptual development (***Theme 5: Positive reinforcement through discussions, conversations, debates, workshop and the interview***). Though there were some limitations as mentioned under the heading 'limitations', the positive impact of the group activities was beyond reproach. This therefore, means that to achieve the best from learners, teachers have to review teaching and learning strategies and methodology by the inclusion of group activities in teaching so that each approach can impact positively on the learners. Bodner (1990: 27) warns "we can teach; and we can teach well, without having the learners learn" in mind.

Classical emphasis on the 'traditional' approach to teaching and learning which gives rise to boredom, extroversion and truancy has to give way to the modern, dynamic and exuberant teaching and learning environment with collaborative working being one of its tools. "The kind of science teaching which learners experience is the most important factor in forming their attitudes towards science" (Ngcoza, 1998: 29). The kind of science teaching that depends on "communicative action", which entails the establishment of an 'open' (creating an atmosphere of trust between the educator and the learner) and 'critical' (subjects to scrutiny the ideologies used in teaching) discourse.

Teachers' sub-standard forms of English precipitated by the fact that the they received inferior education under the Bantu Education Act and continued 'code switching', has affected their proficiency in English and this spills over to the learners. Webb and Ilsley (1997: 481 cited in Ngcoza, 1998: 31) posit that successful teaching of science and mathematics can be constrained by the fact that some teachers lack proficiency in English (***Theme 6: Language proficiency***), which is the recommended medium of instruction in most schools. Learners had difficulty in interpreting some of the questions that constituted the questionnaire and sometimes had problems in expressing their views on issues put before them. This was also revealed during discussions, conversations and debates when learners literally translated situations from the mother tongue into English, which sometimes resulted in a misconception. For example, some learners consider corrugated iron roofing sheets to be made of zinc because in the mother tongue, it is referred to as 'izinc'. At certain times these misconceptions may be the result of miscommunication between the teacher and the learner. Klaasen and Lijnse (1996, cited in Sanger and Greenbowe, 1997: 394) argue that the difference between what learners say and what 'experts' believe is not always due to differences in their beliefs, but instead, may be due to a difference in meaning.

Learners deficiency in English was also confirmed during the interview session where one of the five learners interviewed could not express herself in English and as such resorted to words: "Hmm...Okay...Shii" and so on. Furthermore, during the workshop session, only those learners who were fluent in English communicated the group findings and ideas to the plenary although all the other learners participated actively in their group discussions.

5.3 Recommendations

A further study into the influence of learners' environment on conceptual understanding of redox reactions is recommended. There is a need for designing teaching and learning units taking into account the environmental set-up of the school, not ignoring the availability of resources. When learning experiences are more concrete, related to familiar situations and interactive, 'resistance' often disappears, and learners construct new experience quickly.

Learners need to be challenged with projects, whether as individuals or in groups. Lack of projects may only encourage the textbook mental image of topics learners learn.

Practical activities should be an integral component in science teaching especially topics such as redox (mentioned earlier as perceived to one of the most difficult topics for both learners and teachers). However the nature and way they are administered plays an important role in achieving its desired objective. I recommend that practical activities should be embarked on before the theoretical teaching. In so doing, learners reflect back on what had been observed during the practical lesson when developing conceptual understanding of the topic under discussion.

The teaching of redox reactions in many of today's schools is dominated by algorithm and numerical conceptualisation. It ignores the learner's ability to comprehend redox in real life situations. Even though learners are taught symbolic and phenomena levels, insufficient connections are made between the levels and the information remains mentalised in their long-term memory. I believe learners have probably not made chemical interpretation of natural phenomenon that could be associated to redox reactions. As a recommendation, teachers should use real-life situations to illustrate redox process so that science becomes more relevant to learners. Integration of topics should also be of primary importance. This is where concept maps can play a vital and important role. An area for future study.

Learners should be encouraged to engage in constructive debates, conversations, discussions and workshops so as to motivate them to be active learners. By such an approach learners will appreciate the dynamic nature of science and will accept the modification of their conceptual development.

I also recommend a larger scale research of this project for generalisation.

The last recommendation is a general one, and relates to an holistic and integrated plan of action. Change is a vital and crucial ingredient in every human endeavour. Thus, with or without the implementation of OBE, science teachers' approach to teaching and learning had to undergo change to meet the demands of today's world.

It is imperative for the education authorities to provide laboratories for all schools. For example, teaching science under a tree as is the case in my school, may not motivate or encouragement learners to put in their best to achieve the desired result.

5.4 Credibility and Trustworthiness of the study

In this research, the subjectivity of the learners, their opinions, attitudes, perspectives, conceptual development and understanding together contributed to a degree of bias. Thus I strived to minimise untrustworthiness and maximise credibility. Henning (1995: 30) posits' "validity is generally regarded as credibility of procedures which are articulated succinctly". Thus one cannot evaluate procedures if they are not explicitly stated. Therefore, this study's trustworthiness and credibility lies in the clarity and rich description of how data was collected, managed and processed, and the various strategies employed throughout the inquiry.

Miles and Huberman (1994), LeCompte and Preissle (1993) and Cohen *et al.* (2000) suggest some validation tactics which I believe contribute to the trustworthiness and credibility of this research, were used to verify the conclusions reached in the study. Such validation tactics include the following amongst others: getting feedback from the learners through discussions, conversations, debates, workshop and interviews, checking for researcher effect, replicating findings and crystallisation. The convincing view of Richardson (2000: 934) is that different sources should be used to crystallise our understanding of reality under investigation. Against this background, data collected from the various sources were synthesised so as to present a credible and trustworthy findings.

5.5 Limitations of the study

The study, like any other such undertaking, is bound to have certain shortcomings and Leedy (1997: 125) feels it is unethical and unprofessional not to acknowledge the likelihood of such limitations. With this in mind, I acknowledge that some of the findings in this study may be peculiar to my learners.

One limitation of this study was the learners' English literacy and my lack of understanding Xhosa. The learners lacked proficiency in English, which happens to be the only medium of communication shared by the learners and myself. I believe that a very rich data would have been gathered if the opportunity were there for the learners to communicate their ideas, opinions and perspective in their mother tongue.

It was really difficult to engage the learners in the research project during school sessions due to the fact that they have other school commitments to attend to. Thus I had to resort to Saturdays, which was sometimes inconvenient for the learners.

Lack of equipment and chemicals prevented me from doing as many as possible practical activities with the learners. I had to go begging for chemicals from other schools to carry out a few experiments.

Despite the fact that cooperative learning has many advantages, one of its weaknesses lies in the group report presented by the learners. In this case it became difficult to ascertain if all the members in the group had attained the desired objectives of the activity.

I believe however, that these and other unperceived biases have not affected the findings of this study.

5.6 Conclusion

The journey my learners and I took through the world of redox reactions allowed me to be better informed and perhaps more sensitive to the difficulty learners have in understanding the concepts of redox reactions and also, linking it to real-life events and occurrences. Evidence from the practical activities, discussions, debates, conversations and the workshop, unveiled the interest depicted by the learners, indicating understanding of the significance of oxidation and reduction concepts.

The study illuminates the relevance of using everyday experiences as a means of stimulating learners' interest in redox reactions. It also suggests that the multiple strategies adopted which put applications first, was more motivating to learners than the traditional schema of theory first, application afterwards. Thus the use of practical activities to guide theory has resulted in learners' development of conceptual understanding. The study also demonstrates in very broad terms the motivating effects of the use of a wide range of learning strategies in the teaching and learning of redox concepts. The findings have shown that learners' struggle with English created a gap between possessing views and ideas and communicating them to others.

It is hoped that studies such as this will be taken serious by science teachers and not left to gather dust on a library shelve while we keep on teaching science in the traditional manner.

In the next chapter, I will reflect on my experiences doing the masters programme through course to the thesis.

CHAPTER 6

REFLECTION

> "Never regard study as a duty, but as the enviable opportunity to learn to know the liberating influence of beauty in the realm of the spirit for your own personal joy and to the profit of the community to which your later work belongs" (Albert Einstein cited on http://www.nsfas.org.za)

6.1 Introduction to the chapter

This chapter explores my journey accompanied by the experience gained in doing the masters programme. It starts with an overview of the entire programme and proceeds to illuminate my tears and joys while pursuing the course work. It also exposes the frustrations and the pleasures along the route to success. It highlights the research process and concludes with a reflection on how the M.Ed program has transformed my attitude to life, including my professional responsibilities.

6.2 An overview of the Master's program

As the saying goes: "a thousand miles start with one step". In 2002 when I was called to be a part of the masters' programme, what went through my mind was, "when would I complete this two-year degree"? I started finding excuses to turn down the offer. However, Mrs Gill Boltt inspired me, when she phoned to request that I report for my first contact session. Amidst fear and shyness, I decided to give it a try. It was not easy for me, since I parted ways with serious academic work some time before. To keep pace with the others, I had to be at my books as early as 3am daily. Little did I know that two years would go by like drinking a glass of water. The program has opened a lot of opportunities for me and, to be very honest, I do not regret taking part in this academic adventure.

6.3 M.Ed. Course work

I entered this program, especially the course work component, with fear and doubt of competence as well as a fear that I do not have the ability to complete the degree. Worsening the situation was my first philosophy session, aggravated by the outcome of the first assignment. I put in so much effort to begin on the right footing for the course, only to find that my effort could not meet the requirements of the task. I decided there and then to call it 'a day' or 'quits'. I mentioned this to Mr. K. Ngcoza who said "Billey, do not give up". This was a challenge he put to me and from then I never looked back. As the programme proceeded, lectures became more and more interesting and rewarding. A week before my exams, little Bill was born and I had to suspend reading for a while. It was then that the fear of failure lured its head. However, all went well.

6.4 My research experience

As a tenderfoot, finding my way in a research project, which was qualitative and collaborative by nature, was a story of an uncertain, unpredictable and indeterminate journey into unknown and uncharted territory. The more I ventured into the research, the more uncertain and unpredictable issues turned out to be. This was worsened by the feeling of surprise and anxiety that accompanied the move into the unfamiliar paradigm of constructivism. However as the project proceeded, I became convinced that research, like all other knowing, is a transactional process. I liken a research to a marriage; full of surprises and unpredictable. As it progresses, so exuberance diminishes. However, perseverance and persistence keeps it in shape until the final full stop is done.

The motivation and inspiration came when I started collecting data and compiling my report. It was fascinating to find that someone else's research and findings could highlight issues in my own research. This gave me the impetus to go beyond what they had achieved. My learners were very cooperative and contributed a lot towards this success. I cued into a language period of my learners on a Friday prior to our Saturday meeting and was surprised to observe them preparing for the next practical activity. I could not have gone through this unknown territory without the smiles and positive comments received from Mr. Ken Ngcoza and Sean Harper. They were more determined to help me through this journey than I thought.

6.5 Conclusion

I will say with pride that the course work and thesis have been mutually enriching. I would have 'cursed my stars' if I had not participated in this programme. My friends and community have elevated my status more than I expected. Research shall always be a part of me, as Sean said in one of his comments; "Billey I hope you will not end here". I will like to conclude with this quote

"Learning is generally a risky business because it means moving out from the safety of the known into the unknown and uncontrolled [...] the involvement of emotions in learning, especially any that involves personal risk is inevitable". (Alsop, 1991: 99)

References

Alsop, S. (1991). Science education and effect. *International Journal of Science Education*, **25**(9), 1043 – 1047.

Appleton, K. (1993). Using theory to guide practice: Teaching science from the constructivist perspective. *School Science and Mathematics*, **93**(5), 269 – 274.

Barker, L. and Johnson, G. (1998). Interview talk as professional practice. *Language and Education*, **12**(4), 229 – 242.

Bennet, N. and Dunn, E. (1994). How children learn: Implications for practice. In B. Moon and A. Mayes (Eds.), *Teaching and learning in the secondary school* (pp. 50 –56). London: Routledge.

Bieger, G. and Gerlach, G. (1996). *Educational research: A practical approach.* Albany: Delmer Publishers.

Blaxter, L., Hughes, C. and Tight, M. (1996). *How to research.* Buckingham: Open University Press.

Blignaut, E., de Villiers, J., Finnemore, D., Gibbon, D., Hicks, D., Jordaan, F. and Marias, P. (1988). *Modular teacher's guide for the teaching of senior physical science (2).* Stellenbosch: The Institute for Mathematics and Science Teaching, University of Stellenbosch.

Bodner, G. (1986). Constructivism: A theory of knowledge. *Journal of Chemical Education*, **63**(10), 873 – 891.

Cohen, L. and Manion, L. (1985). *Research methods in education* (2nd ed.). London: Croom Helm.

Cohen, L., Manion, L. and Morrison, K. (2000). *Research methods in education* (5th ed.). London: Routledge.

Creswell, J. (1994). *Research design: Qualitative and quantitative approach.* Thousand Oaks, CA: Sage.

De Vos, A. (1998). *Research at grass roots: A primer for the caring profession.* Pretoria: J. L.Van Schaik.

Department of Education. (1997). *Curriculum 2005: Life long learning for the 21st century.* Retrieved February 4th 2003 from the World Wide Web: http//www.polity.org.za/html/govdocs/misc/curr2005html

Department of Education. (2000). *Revised national curriculum statement: Grades 0 – 9.* Pretoria: Department of Education

Department of Education. (2002). *National curriculum statement: Grades 10 – 12* (Draft). Pretoria: Department of Education.

Eisner, E. and Peshkin, A. (1990). *Qualitative inquiry in education.* New York: Teachers College Press.

Ely, M., Anzul, M., Friedman, T., Garner, D. and Steinmets, A. (1991). *Doing qualitative research: Circles within circles.* London: Falmer Press.

Erickson, F. (1998). Qualitative methods for science education. In J. Fraser and G. Tobin (Eds.), *International handbook of science education* (pp.1155-1173). Dordrecht: Kluwer.

Etcheberger, M. and Shaw, K. (1992). Teacher change as a progression of transitional images: A chronology of developing a constructivist teacher. *School Science and Mathematics*, **92**(8), 411 – 417.

Fontana, A. and Frey, J. (1994). The interview: From structured questions to negotiated text. In N. K. Denzin and Y. S. Lincoln (Eds.), *Handbook of qualitative research* (2nd ed.) (pp. 645 - 673). Thousand Oaks, CA.: Sage.

Freeman, D. (1998). *Doing teacher research: From inquiry to understanding.* Boston: Heinle and Heinle.

Galbraith, L. Carss, C., Endean, L., Grice, D. and Warry, M. (1997). Towards scientific literacy for the third millennium: A view from Australia. *International Journal of Science Education,* **19**(4), 447 – 467.

Gardner, H. (1999). *The disciplined mind: What all students should understand.* London: Simon and Schuster.

Garnett, J., Garnett, P. and Treagust, D. (1990). Implications of research on students' understanding of electrochemistry for improving science curricula and classroom practice. *International Journal of Science Education*, **12**(2), 147 – 156.

Gott, R. and Duggan, S. (1996). Practical work: Its role in the understanding of evidence in science. *International Journal of Science Education*, **18**(7), 791 – 806.

Henning, E. (1995). Qualitative educational research: Soft or solid options? *South African Journal of Education*, **16**(2), 3 –20.

Hinchey, P. (1998). Rethinking what we know: Positivist and constructivist epistemology. In P. Hinchey (Ed.), *Finding freedom in the classroom: A practical introduction to critical theory* (pp. 35 – 60). New York: P. Lang.

Hitchcock, H. and Hughes, D. (1995). *Research and the teacher* (2nd ed.). London: Routledge.

Hodson, D. (2003). Time for action: Science education for an alternative future. *International Journal of Science Education*, **25**(6), 645 – 670.

Irwin, P. (2002). *An introduction to surveys and to the uses and construction of questionnaires.* Unpublished paper presented at a research methods course, Education Department, Rhodes University, Grahamstown.

Janse van Rensburg, E. (2001). *An orientation to research.* Rhodes Environmental Education Unit research methods short course, Rhodes University, Grahamstown.

Jansen, J. (1999). Why outcomes-based education will fail: An elaboration. In J. Jansen and P. Christie (Eds.), *Changing curriculum: Studies based on outcomes-based education in South Africa.* Cape Town: Juta and Co Ltd.

Klu, E. (2000). *Issues of language, linguistics and pedagogy in the continuous professional development of teachers in English in Bushbuckridge.* Unpublished doctoral thesis, Rand Afrikaans University, Johannesburg.

Kvale, S. (1996). *Interviews.* London: Sage.

Larochelle, M. (2000). Radical constructivism: Notes on viability, ethics and other educational issues. In L. Steffe and P. Thompson (Eds.), *Radical constructivism in action: Building on the pioneering work of Ernst von Glasersveld* (pp. 55 – 65). London: Routledge.

Lather, P. (1991). *Getting smart: Feminist research and pedagogy within the post modern.* New York: Routledge.

LeCompte, M. and Preissle, J. (1993). *Ethnography and qualitative design in education research* (2nd ed). New York: Academic Press.

Leedy, P. (1997). *Practical research: Planning and design* (6th ed). Upper Saddle River, N. J.: Merrill.

Lincoln, Y. and Guba, G. (1985). *Naturalistic inquiry.* Beverly Hills: Sage.

Lotz, H. (1996). *The development of environmental education resource material for junior primary education through teacher participation: The case of We Care primary project* (pp. 77 – 110). Unpublished doctoral dissertation, University of Stellenbosch, Stellenbosch.

Lotz, H. (1999). *Environmental education in curriculum transformation.* Unpublished paper presented at the Eastern Cape SADTU provincial curriculum development workshop, East London.

Marshall, C. and Rossman, B. (1989). *Qualitative research.* London: Sage.

Matthews, R. (1992). *Old wine in new bottles: A problem with constructivist epistemology.* Auckland: University of Auckland.

Maykut, P. and Morehouse, R. (1994). *Beginning qualitative research: A philosophic and practical guide.* London: Falmer Press.

McGhan, B. (1994). The possible outcomes of outcomes-based education. *Educational Leadership,* **50**(8), 70 – 72.

Merriam, S. (2001). *Qualitative research and case study application in education.* San Francisco: Jossey-Bass.

Miles, M. and Huberman, M. (1994). *Qualitative data analysis: A sourcebook of new methods.* London: Sage.

Millar, R. (1996). Towards a science curriculum for public understanding. *School Science Review*, **77** (280), 8 – 18.

Newton, D. (1988). Relevance and science education. *Educational Philosophy and Theory*, **20**(2), 7 – 12.

Ngcoza, K. (1998). *What are museums for? : A case study on the benefits of using the museum's science programmes.* Unpublished masters thesis, Rhodes University, Grahamstown.

Oppenheim, A. (1992). *Questionnaire design, interviewing and attitude measurement.* London: Heinemann

Ozmon, H. and Craver, S. (1986). *Philosophical foundations of education* (3rd ed.). Columbus: Merrill.

Pahad, M. (1999). Outcomes-Based assessment: The need for a common vision of what counts and how to count it. In J. Jansen and P. Christie (Eds.), *Changing curriculum: Studies based on Outcomes-Based Education in South Africa.* Cape Town: Juta.

Patton, M. (1990). *Qualitative evaluation of research methods* (2nd ed.). Newbury Park: Sage.

Pliska, A. and McQuade, J. (1994). Pennsylvania battle for student learning outcomes. *Educational Research*, **50**(8), 66 – 69.

Pollard, E. and Liebeck, H. (Eds.). (1994). *The Oxford paperback dictionary* (4th ed.) Oxford: Oxford University Press.

Posner, G. and Gertzog, W. (1982). The clinical interview and the measurement of conceptual change. *Science Education,* **66**(2), 195 – 209.

Rasool, M. (1999). Critical responses to Why OBE will fail". . In J. Jansen and P. Christie (Eds.), *Changing curriculum: Studies based on Outcomes-Based Education in South Africa.* Cape Town: Juta and Co Ltd.

Resnick, L. (1983). Mathematics and science learning. *A New Conception Science*, **220**, 477 – 478.

Richards, J. and Rodgers, C. (1995). *Beyond training.* New York: Cambridge University Press.

Richardson, L. (2000). A method of inquiry. In N. Denzin and Y. Lincoln (Eds.), *Handbook of qualitative research* (2nd ed.) (pp 923 – 949). London: Sage.

Ringnes, V. (1995). Oxidation-reduction – learning difficulties and choice of redox models. *School Science Review*, **77**(279), 74 – 78.

Rogan, M. and Grayson, D. (2002). Towards a theory of curriculum implementation with particular reference to science education in developing countries. Forthcoming. *International Journal of Science Education.* January 2002.

Rollnick, M., Zwane, S., Staskun, M., Lotz, S. and Green, G. (2001). Improving pre-laboratory preparation of first year university chemistry students. *International Journal of Science Education,* **23**(10), 1053 – 1071.

Roschelle, J. (2003). *Learning in interactive environments: Prior knowledge and new experience.* Retrieved May 13th 2003 from World Wide Web. http://www.explotorium.edu/IFI/resources/museumeducation/priorknowlegde.html

Sanger, M. and Greenbowe, T. (1997). Common student misconceptions in electrochemistry: Galvanic, electrolytic and concentration cells. *Journal of Research in Science Teaching,* **34**(4), 377 – 398.

Silverman, D. (1993). *Interpreting qualitative data: Methods for analysing talk, text and interaction.* London: Sage.

Silverman, D. (2000). *Doing qualitative research: A practical handbook.* London: Sage.

Sisler, H. and Van der Werf, C. (1980). Oxidation-reduction: An example of chemical sophistry. *Journal of Chemical Education,* **57**(1), 42-44.

Soudani, M., Sivade, A., Cros, D. and Medimagh, M. (2000). Transferring knowledge from the classroom to the real world: Redox concepts. *School Science Review,* **82**(298), 64-72.

Stake, R. (1995). *The art of case study research.* Thousand Oaks, CA: Sage Publications.

Tiber, K. (2001). The mismatch between assumed prior knowledge and the learner's conceptions: A typology of learning impediments. *Education Studies,* **27**(2), 159 –171.

Van Harmelen, U. (1995). Behaviorism, empiricism and education. In P. Higgs (Ed.), *Metatheories in philosophy of education* (pp. 51 – 67). Johannesburg: Heinemann.

Van Harmelen, U. (2000). *Introduction to education theory and practice: Linking theory and practice.* Education core text 1. Education Department, Rhodes University, Grahamstown.

Van Manen, M. (1977). Linking ways of knowing with ways of being practical. *Curriculum Inquiry,* **6,** 205 – 208.

Vockell, E. and Asher, J. (1995). *Educational research* (2nd ed.). New York: Prentice Hall.

Von Glasersveld, E. (1987). Learning as a constructivist activity. In C. Janvier (Ed.), *Problems of representation in the teaching and learning of mathematics* (pp. 3 – 17). Hillside: Erlbaum.

Weber, W. (1972). Competency-based teacher education. In R. Huston (Ed.), *Strategies and resources for developing a competency-based teacher education.* New York State Education Department, New York.

White, R. and Gunstone, R. (1998). Probing understanding. In J. Fraser and G. Tobin (Eds.), *International handbook of science education* (pp187 –201). London: Kluwer.

Wilson, J. and Stenvold, M. (1988). *Five ways research suggests to improve laboratory instruction.* An article presented at the national meeting of the Society for College Science Teaching. St. Louis, April 8, 1988.

Wilson, N. and McLean, S. (1994). *Questionnaire design: A practical introduction.* Newtown Abbey: University of Ulster Press.

Wright, M. (1978). *Progress in education: A review of schooling in England and Wales.* London: Croom Helm.

Zeichner, K. (1993). Traditions of practice in United States. Pre-service teacher education. *Journal of Teaching and Teacher education*, **9**(1), 1 – 13.

Appendix A

PRE-INTERVENTION QUESTIONNAIRE – (BACKGROUND INFORMATION)

This questionnaire forms part of my research on the topic oxidation – reduction (redox) reactions. You should feel very free and express yourself as much as you wish. I undertake to protect your identity and treat all information provided as confidential.

Part A – Social and Academic Background Information.

1. Distribution Date: .... 2 Serial number: ....

3. Age:........ 4. Gender:...........

5. Name of School:................

6. Your present grade:.............

7. Mention three of your most favourite subjects in order of preference.

   (a)...................... (b)........................... (c)......................

8. How do you feel about science as a subject:.................................

   ....

9. Describe your most interesting science topic in your previous grade and what made you to enjoy this topic?

   ....

   ....

   ....

Part B – Elicitation of Prior Knowledge

1. Combustion is one of the topics you studied in your previous grade.

   How do you feel about this topic in general?

   What have you learnt from this topic

   Describe briefly what combustion is all about.

   What are the essential components of combustion?

2. In your Biology lessons, some of the important topics you studied were photosynthesis, respiration and metabolism. Kindly express your understanding of these topics.

3. What role does oxygen play in all the processes described above (respiration, photosynthesis and metabolism)?
4. Briefly discuss oxidation and reduction reactions.
5. How would you describe combustion, respiration, photosynthesis and metabolism in terms of oxidation – reduction reaction?

Appendix B

PRE-INTERVENTION ACTIVITIES AND WORKSHEET

These activities seek to probe learners' prior knowledge of oxidation – reduction reactions

ACTIVITY 1

TOPIC: Combustion Reaction – Reaction of oxygen with substances such as Carbon, Sulphur and Magnesium

Introduction: This unit aims to highlight the contribution of scientific knowledge, principles and laws to the enhancement of nearly every aspect of the contemporary and technological driven life and products. It is important that we take a close look at these processes not only because it affect us in our daily lives but also to have an understanding of what happens at the invisible atomic and molecular level.

Despite the positive contribution of combustion towards easy life of human beings, it has also created problems, which cannot be ignored. These include the 'greenhouse effect' caused by excessive atmospheric carbon dioxide, 'acid rain' an effect of emission of sulphur dioxide into the atmosphere, which dissolves in the rain as it falls and lastly to be mentioned is 'corrosion' caused by the reaction of oxygen in the air with iron in the presence of water vapour.

Equipment and Chemicals

1. Radmaste microchem kit
2. Cotton wool
3. Box of matches
4. Mangenese dioxide
5. Hydrogen peroxide
6. Limewater
7. Carbon powder
8. Sulphur powder
9. Magnesium ribbon
10. Tap water

Method

1. Use the spooned end of a plastic microspatula to place one level spatula of manganese dioxide powder into well F[1]
2. Fill3/4 of the well F[6] with fresh lime water.
   Describe the appearance of the limewater
3. Push lid 1 securely into well F[1]. Attach one of the silicone tubes to the tube connector on the lid.

4. Push lid 2 securely into well F[6]. Make sure that the vent in the lid face upwards. Attach the other silicone tube to the tube connector on the lid 2.
5. Fill the syringe with 1 ml of the 10% hydrogen peroxide solution.
6. Fit the syringe into the syringe inlet on well F[1].
7. Twirl a small piece of cotton wool around the pointed end of a toothpick. Dip the end with the cotton wool into a little water to moisten the cotton wool.
8. Push the toothpick through the glass tube. This will wet the inner wall of the tube so that carbon powder adheres to the inside of the tube and prevents it from moving along the tube during heating.
9. Hold the glass tube in a horizontal position. Use the narrow end of a clean microspatula to place a small quantity of carbon powder in the centre of the glass tube.
10. Keep the glass tube in a horizontal position and attach one end of the glass tube to the silicone tube on lid 1. Connect the other end of the glass tube to the silicone on lid 2.
11. Light the microburner and place it on one side
12. Slowly add about 0,4ml of the 10% hydrogen peroxide from the syringe into well F[1]. Wait for a steady stream of bubbles to appear in the limewater in well F[6]. Now begin to heat the carbon powder in the glass tube with the microburner.
13. If the bubbles stop flowing in well F[6], add more of the hydrogen peroxide dropwise to the well F[1]while continuing to heat the carbon.
14. Heat the carbon for 2minute.

    Describe the appearance of the limewater in well F[6] after about 2minutes.
15. After a change has been noted in the limewater, continue to heat the carbon in the glass tube for another 2 – 3 minutes.
16. Blow out the microburner flame. Disconnect lid 2 from well F[6] to avoid limewater being sucked back into the glass tube.
17. Repeat the procedure using sulphur powder and clear tap water instead of limewater and record your observations.
18. Again go through all the procedure this time using magnesium ribbon and tap water.
19. Blow out the microburner at the end of each process.
20. Tabulate your observation in the table below.

Table 1

Substance burnt	Does substance burn in oxygen	Colour of flame	Phase of product formed	Name of oxide	Colour change of solution in well F[6] with litmus paper
Carbon					
Sulphur					
Magnesium					

Worksheet

1. Does oxygen support combustion? Yes............ No...........
2. What do you think happened to the various substances in the glass tube during heating?

   (a) Carbon..

   (b) Sulphur...

   (c) Magnesium..
3. Write a balanced chemical equation for all the three reactions.

   ....
4. Combustion is classified as an oxidation –reduction reaction. Identify the following.

   The substance that undergoes oxidation. ....

   The substance that undergoes reduction ....
5. Which definition for redox have you applied? ....
6. Mention two types of energy released during the process ....

7. Was energy transferred in the process? Yes........ No.........
8. In your own understanding, describe why combustion reaction is a redox reaction

   ....

End of Activity 1

ACTIVITY 2

TOPIC: Reaction of some metals with solutions of other metal salts.

Introduction: The compounds of metals with certain non-metals and with groups ao atoms like sulphates (SO_4 group) and nitrates (NO_3 group) are called salts. Common salt is a compound of the metal sodium and the non-metal chlorine. We are going to demonstrate how metals react with solutions of other metal salts and link the reactions to oxidation and reduction.

Equipment and Chemicals

1. Radmaste microchem kit 2. magnesium powder 3. zinc powder 4. iron powder 5. copper powder 6. concentrated solution of magnesium sulphate 7. concentrated solution of zinc sulphate 8. concentrated solution of iron(II)sulphate 9. concentrated solution of copper (II) sulphate

Method

1. Half filled the 12 wells of the combo plate A_1 to A_{12} with 3 each of the prepared concentrated solutions ($MgSO_{4(aq)}$, $ZnSO_{4(aq)}$, $FeSO_{4(aq)}$ and $CuSO_{4(aq)}$).
2. Using a spatula, add the respective metal powders to the solutions in the well facilitated by the teacher.
3. Observe what happens in each well. Wait for 2 to 3 minutes to confirm your observation. Record your findings in the table as shown below. Indicate in each case either a tick or a cross if a reaction takes place or not. Then write a detailed observation

Table 2

Metals	Metal salt solutions			
	$MgSO_4$	$ZnSO_4$	$FeSO_4$	$CuSO_4$
Mg				
Zn				
Fe				
Cu				

Worksheet

1. Write balanced chemical equations for all your observations.
    - ....
    - ....
    - ....
2. Arrange the metals in decreasing order of their tendency to react with aqueous solutions of the metal salts. ....
3. Use your observation to explain what happens between magnesium and copper sulphate solution? ....
4. In all your observed reaction, identify the substance that is oxidised and the one that is reduced.

Oxidised	Reduced
1.	
2.	
3.	
4.	
5.	
6.	

5. Relate your observation and your reactivity series in question 2 to the oxidation of the metals..

6. Interpret your reactivity series in terms of oxidation –reduction by completing the table below

Oxidising Agent	No of metals oxidised
Mg^{2+}	0
	1
	2
	3

Reducing Agent	No of metals reduced
Mg	3
	2
	1
	0

7. From your deductions above, state :
   - The strongest oxidising agent.........................
   - The weakest oxidising agent.........................
   - The strongest reducing agent.........................
   - The weakest reducing agent.........................
   - The strongest oxidising agent forms.................reducing agent
   - The weakest reducing agent forms.................oxidising agent.

End of Activity 2

Appendix C

TEACHING AND LEARNING UNIT

INTRODUCTION

Historical background

Lavoisier A. L. (1743 – 1794) a French chemist was the first person to introduce the term 'oxidation' after he realized that combustion involves the combination of a substance with oxygen. Before then, "phlogiston" (Greek: 'fire – stuff') theory was accepted by all scientists. This theory regarded heat as a type of "fire substance" which escapes from a substance on heating. Lovoisier's finding gave rise to the traditional concept and definition of oxidation as the addition of oxygen to a substance and the removal of oxygen as reduction. This concept of addition and removal of oxygen as redox persisted for many years and in the course of time it became clear that the two processes occur simultaneously. In 1837, J. Liebig proposed another definition of 'redox'. He defined redox in terms of removal and addition of hydrogen.

With the appearance of the periodic classification of elements, it came to light that non-metals such as sulphur, chlorine and iodine behave similarly to oxygen (they can easily combine with substances). This serves as a limitation to the Lavoisier and Liebig definition of oxidation. G.A. Lewis (1916) with his electronic theory of valence laid the ground for defining redox reactions as a reaction with the transfer of electrons. However, the terms 'oxidation' and 'reduction' are today connected to change in oxidation numbers Indicating the quantity of electron(s) gained or lost), a term introduced by W. Latimer.

Definition of Oxidation and Reduction

The rusting of metals, the process involved in photography, the way living systems produce and utilize energy, and the operation of a car battery, are but a few examples of a very common and important type of chemical reaction. These chemical changes are all classified as "electron-transfer" or oxidation-reduction reactions.

The term, oxidation, was derived from the observation that almost all elements reacted with oxygen to form compounds called, oxides. A typical example is the corrosion or rusting of iron as described by the chemical equation:

$4\ Fe + 3\ O_2$ -----> $2\ Fe_2O_3$

Reduction, was the term originally used to describe the removal of oxygen from metal ores, which "reduced" the metal ore to pure metal as shown below:

$2\ Fe_2O_3 + 3\ C$ -----> $3\ CO_2 + 4\ Fe$

Based on the two examples above, oxidation can be defined very simply as, the "addition" of oxygen; and reduction, as the "removal" of oxygen. But there is a lot more to "oxidation-reduction". However the definitions above could not satisfy all redox reactions. This the called for more appropriate definitions for the process resulting in three other concepts and definitions:

1. The addition of hydrogen to a substance (an ion, atom, molecule or element) as reduction and removal of hydrogen from a substance as oxidation.

2. The loss or donation of electrons by an atom, molecule or an ion as oxidation and reduction as the gain or acceptance of electrons by an atom, a molecule or an ion. This definition seems to be the dominant definition for redox. This is simplified as:

OIL – Oxidation Is Loss (of electrons) / LEO – Loss of Electrons is Oxidation

RIG – Reduction Is Gain (of electrons) / GER – Gain of electrons is Reduction

3 Increase in oxidation number as oxidation and a decrease in oxidation number as reduction.

To summarize the above:

- Addition and removal of oxygen as redox reactions, which I refer to as the 'oxygen model' or the 'traditional concept'.
- Removal and addition of hydrogen as a redox reaction, referred to as the 'hydrogen model' (traditional concept)
- Electron transfer theory and
- Oxidation number model (I refer to the last two as the modern concepts and definitions).

Summary of redox concepts and definitions

MODEL	*BASIC DEFINITION*	
	OXIDATION	***REDUCTION***
❖ *Oxygen model*	*Gain of oxygen*	*Loss of oxygen*
❖ *Hydrogen model*	*Loss of hydrogen*	*Gain of hydrogen*
❖ *Electron transfer*	*Loss of electron*	*Gain of electron*
❖ *Oxidation number*	*Increase in oxidation number*	*Decrease in oxidation number*

OXIDIZING AND REDUCING AGENTS DEFINITION

Oxidizing Agent is a substance which *oxidizes something else* and itself reduced.

Reducing Agent is a substance that reduces another reagent and itself oxidised.

CONCEPTS

Basic Concepts

- Oxidation States/Oxidation Numbers
- Oxidation-Reduction Reactions; A Basic Model
- Ionic Compounds
- Ionic Formulas
- Ionic Compounds Involving Transition Metals

Extended Concepts

- Concept of Electronegativity
- Electronegativity of Metals and Nonmetals
- Redox Reactions Involving Nonmetals Only
- Types of Redox Reactions
    - Combination
    - Decomposition
    - Single Displacement
- Balancing Redox Reactions Using the Half Reaction Method

Everyday Examples

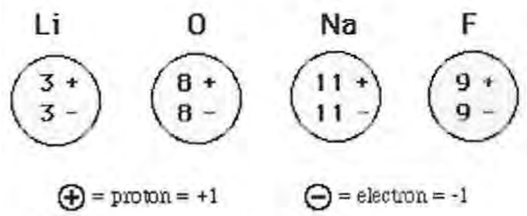
Oxidation-reduction reactions have many far-reaching applications in our lives. Some of these applications are so common, that we take them for granted; others are not so obvious. The following are just a few examples of oxidation-reduction reactions.

- Bleaching Agents
- Photosynthesis
- Metabolism
- Nitrogen Fixation
- Combustion
- The Dry Cell Battery
- Electrochemistry
- Photo-oxidation (Photography Æ Glasses)
- Corrosion

OXIDATION STATE AND OXIDATION NUMBERS

The logical starting point in the discussion of oxidation-reduction reactions is the atom, and the terms and conventions used by chemists in describing this phenomenon.

All atoms are electrically neutral even though they are comprised of charged, subatomic particles. The terms, oxidation state or oxidation number, have been developed to describe this "electrical state" of the atom. The oxidation state or oxidation number of an atom is simply defined as the sum of the negative and positive charges in an atom. Since every atom contains equal numbers of positive and negative charges, the oxidation state or oxidation number of any atom is always zero. This is illustrated by simply totaling the opposite charges of the atoms as shown by the following examples.



Note, in every instance the sum of the positive and negative charge is zero; hence the oxidation state of any atom is always zero.

HOW TO ASSIGN OXIDATION NUMBERS

Assigning all atoms an oxidation state of zero serves as an important reference point, as oxidation-reduction reactions always involve a change in the oxidation state of the atoms or ions involved. This change in oxidation state is due to the "loss" or "gain" of electrons. The loss of electrons from an atom produces a positive oxidation state, while the gain of electrons results in negative oxidation states.

The changes that occur in the oxidation state of certain elements can be predicted quickly and accurately by the use of simple guidelines. These guidelines are based on the behavior of the Representative Elements, which can be divided into two classes; the metals and nonmetals.

All metal atoms are characterized by their tendency to be oxidized, losing one or more electrons, forming a positively charged ion, called a cation. During this oxidation reaction , the oxidation state of the metal always increases from zero to a positive number, such as "+1, +2, +3...." , depending on the number of electrons lost. The number of electrons lost by these Representative metals and the charge of the cation formed are always equal to the Group number of the metal as summarized below.

Group Number	Number of Electrons Lost	Charge of Cation Formed
I	1	+1
II	2	+2
III	3	+3
IV	4	+4

The group numbers also correspond to the electrons that are found in the outermost energy levels of these atoms. These electrons are often called valence electrons.

By convention oxidation reactions are written in the following form using the element, Calcium, as an example

Symbol of the atom		Symbol of the cation formed		Number of electrons lost
Ca	$\longrightarrow$	Ca^{+2}	+	$2e^-$

Note that the oxidation state increases from zero to a positive number (from "0" to "+2" in the above example) and is always numerically equal to the number of electrons lost.

The electrons lost by the metal are not destroyed but gained by the nonmetal, which is said to be reduced. As the nonmetal gains the electrons lost by the metal, it forms a negatively charged ion, called an anion. During this reduction reaction, the oxidation state of the nonmetal always decreases from zero to a negative value (-1, -2, -3) depending on the number of electrons gained. The number of electrons gained by any Representative nonmetal and the charge of the anion formed, can be predicted by use of the following guidelines.

Group Number	Number of Electrons Gained	Charge of Anion Formed
IV	4	-4
V	3	-3
VI	2	-2
VII	1	-1
VIII	0	no tendency to form anions

The GROUP VIII nonmetals have no tendency to gain additional electrons, hence they are unreactive in terms of oxidation-reduction. This is one the reasons why this family of elements was originally called the Inert Gases.

By convention reduction reactions are written in the following way:

$$\overset{\underline{\text{Symbol of the atom}}}{O} + \overset{\underline{\text{Number of electrons gained}}}{2e^-} \longrightarrow \overset{\underline{\text{Symbol of the anion formed}}}{O^{-2}}$$

Note that the charge of anion formed is always numerically equal to the number of electrons gained.

One important fact to remember in studying oxidation-reduction reactions is that the process of oxidation cannot occur without a corresponding reduction reaction. Oxidation must always be "coupled" with reduction, and the electrons that are "lost" by one substance must always be "gained" by another as matter (such as electrons) cannot be destroyed or created. Hence, the terms "lost or gained", simply mean that the electrons are being transferred from one particle to another.

Balancing Redox Reactions Using the Half Reaction Method

Many redox reactions occur in aqueous solutions or suspensions. In this medium most of the reactants and products exist as charged species (ions) and their reaction is often affected by the pH of the medium. The following provides examples of how these equations may be balanced systematically. The method that is used is called the ion-electron or "half-reaction" method.

Example 1 -- Balancing Redox Reactions Which Occur in Acidic Solution

Organic compounds, called alcohols, are readily oxidized by acidic solutions of dichromate ions. The following reaction, written in net ionic form, records this change. The oxidation states of **each atom in each compound** is listed in order to identify the species that are oxidized and reduced, respectively.

$$\underset{+6\ \ -2}{\overset{\text{dichromate ion}}{(Cr_2O_7)^{-2}}} \quad + \quad \underset{-2\ +1\ -2}{\overset{\text{alcohol}}{C_2H_6O}} \quad \text{---->} \quad \underset{+3}{\overset{\text{chromium (III)}}{Cr^{+3}}} \quad + \quad \underset{-1\ \ +1\ -2}{\overset{\text{acetaldehye}}{C_2H_4O}}$$

An examination of the oxidation states, indicates that carbon is being oxidized, and chromium, is being reduced. To balance the equation, use the following steps:

1. First, divide the equation into two halves; an oxidation half-reaction and reduction half-reaction by grouping appropriate species.

3. The third step involves balancing oxygen atoms. To do this, one must use water (H_2O) molecules. Use 1 molecule of water for each oxygen atom that needs to be balanced. Add the appropriate number of water molecules to that side of the equation required to balance the oxygen atoms as shown below.

   (red.) $(Cr_2O_7)^{-2}$ ----> $2\ Cr^{+3}$ + $7\ H_2O$

   (ox.) C_2H_6O ----> C_2H_4O
   (as there are equal numbers of oxygen atoms, skip this step for this half-reaction)

4. The fourth step involves balancing the hydrogen atoms. To do this one must use hydrogen ions (H^+). Use one (1) H^+ ion for every hydrogen atom that needs to balanced. Add the appropriate number of hydrogen ions to that side of the equation required to balance the hydrogen atoms as shown below

   (red.) $14\ H^+$ + $(Cr_2O_7)^{-2}$ ---> $2\ Cr^{+3}$ + $7\ H_2O$
   (as there are 14 hydrogen atoms in 7 water molecules, 14 H^+ ions must be added to the opposite side of the equation)

   (ox.) C_2H_6O ---> C_2H_4O + $2\ H^+$
   (2 hydrogen ions must be added to the "product" side of the equation to obtain a balance)

5. The fifth step involves the balancing of positive and negative charges. This is done by adding electrons (e-). Each electron has a charge equal to (-1). To determine the number of electrons required, find the net charge of each side the equation.

(red)	$14H^+$ + $(Cr_2O_7)^{-2}$ ----------->	$2\ Cr^{+3}$ + $7H_2O$
charge:	[+14 -2]	[2(+3) + 0]
net charge:	**+12**	**+6**

The electrons must always be added to that side which has the greater positive charge as shown below.

	6e- + $14H^+$ + $(Cr_2O_7)^{-2}$ ----------->	$2\ Cr^{+3}$ + $7H_2O$
charge	(-6) (+14) (-2)	(+6) + (0)
net charge:	**+6**	**+6**

note: the net charge on each side of the equation does not have to equal zero.

The same step is repeated for the oxidation half-reaction.

(ox)	C_2H_6O	-->	C_2H_4O + $2H^+$
charge:	(0)		(0) + (+2)
net charge:	**0**		**+2**

As there is a net charge of +2 on the product side, two electrons must be added to that side of the equation as shown below.

	C_2H_6O	-->	C_2H_4O + $2H^+$ + **2e-**
charge:	(0)		(0) + (+2) (-2)
net charge:	**0**		**0**

At this point the two half-reactions appear as:

(red) $6e^- + 14\,H^+ + (Cr_2O_7)^{-2}$ -------> $2\,Cr^{+3} + 7\,H_2O$

(ox) C_2H_6O ------> $C_2H_4O + 2\,H^+ + 2e^-$

The reduction half-reaction requires 6 e-, while the oxidation half-reaction produces 2 e-.

6. The sixth step involves multiplying each half-reaction by the smallest whole number that is required to equalize the number of electrons gained by reduction with the number of electrons produced by oxidation. Using this guideline, the oxidation half reaction must be multiplied by "3" to give the 6 electrons required by the reduction half-reaction.

   (ox.) $3\,C_2H_6O$ ---> $3\,C_2H_4O + 6\,H^+ + 6e^-$

7. The seventh and last step involves adding the two half reactions and reducing to the smallest whole number by cancelling species which on both sides of the arrow.
8. 14. $6e^- + 14\,H^+ + (Cr_2O_7)^{-2}$ -----> $2\,Cr^{+3} + 7\,H_2O$

   $3\,C_2H_6O$ -----> $3\,C_2H_4O + 6\,H^+ + 6e^-$

   adding the two half-reactions above gives the following:

   $6e^- + 14H^+ + (Cr_2O_7)^{-2} + 3C_2H_6O$ ---> $2Cr^{+3} + 7H_2O + 3C_2H_4O + 6H^+ + 6e^-$

   Note that the above equation can be further simplified by subtracting out 6 e- and 6 H^+ ions from both sides of the equation to give the final equation.

   $6e^- + 14H^+ + (Cr_2O_7)^{-2} + 3\,C_2H_6O$ ---> $2\,Cr^{+3} + 7\,H_2O + 3\,C_2H_4O + 6\,H^+ + 6e^-$
   $- 6e^-$ $- 6\,H^+$ **$- 6\,H^+$ $- 6e^-$**

   $8\,H^+ + (Cr_2O_7)^{-2} + 3\,C_2H_6O$ ----> $2\,Cr^{+3} + 3\,C_2H_4O + 7\,H_2O$

   Note: the equation above is completely balanced in terms of having an **equal number of atoms as well as charges.**

Example 2 - Balancing Redox Reactions in Basic Solutions

The active ingredient in bleach is the hypochlorite (OCl^-) ion. This ion is a powerful oxidizing agent, which oxidizes many substances under basic conditions. A typical reaction is its behavior with iodide (I^-) ions as shown below in net ionic form.

$I^-(aq) + OCl^-(aq)$ ------> $I_2 + Cl^- + H_2O$

Balancing redox equations in basic solutions is identical to that of acidic solutions except for the last few steps as shown below.

1. First, divide the equation into two halves; an oxidation half-reaction and reduction-reaction by grouping appropriate species.

2. 2. (ox) I^- ----> I_2

3. 3.

(red) OCl^- ----> Cl^- + H_2O

4. Second, if needed, balance both equations, by inspection ignoring any oxygen and hydrogen atoms. (The non-hydrogen and non-oxygen atoms are already balanced,hence skip this step)
5. Third, balance the oxygen atoms using water molecules. (The hydrogen and oxygen atoms are already balanced; hence, skip this step also.
6. Fourth, balance any hydrogen atoms by using an (H+) for each hydrogen atom

(ox) 2 I^- ----> I_2

(as no hydrogens are present, skip this step for this half-reaction)

(red) 2 H^+ + OCl^- -----> Cl^- + H_2O

(two hydrogen ions must be added to balance the hydrogens in the water molecule).

7. Fifth, use electrons (e-) to equalize the net charge on both sides of the equation. Note; each electron (e-) represents a charge of (-1).

(ox)		$2I^-$			---->	I_2	+	$2e^-$		
	charge:	(-2)				(0)	+	(-2)		
	net charge:	0					0			
(red)		$2e^-$	+ 2 H+	+ OCl^-	------>	Cl-		+		H2O
	charge:	(-2)	(+2)	(-1)		(-1)		+		(0)
	net charge:		-1					-1		

8. Sixth, equalize the number of electrons lost with the number of electrons gained by multiplying by an appropriate small whole number.
9. 9. (ox) 2 I^- ----> I_2 + $2e^-$

(red) $2e^-$ + 2 H^+ + OCl^- ----> Cl^- + H_2O

(as the number of electrons lost equals the number of electrons gained, skip this step)

10. Add the two equations, as shown below.

2 e^- + 2 I^- + 2 H^+ + OCl^- ----> I_2 + Cl^- + H_2O + $2e^-$

and subtract "like" terms from both sides of the equation. Subtracting "2e-" from both sides of the equation gives the net equation:

$$\begin{array}{l}
2e^- + 2I^- + 2H^+ + OCl^- \text{------->} I_2 + Cl^- + H_2O + 2e^- \\
\underline{-\,2e^- \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad -\,2e^-} \\
\quad 2I^- + 2H^+ + OCl^- \text{------->} I_2 + Cl^- + H_2O
\end{array}$$

11. To indicate the fact that the reaction takes place in a basic solution, one must now add one (OH-) unit for every (H+) present in the equation. The OH- ions **must be added to both sides of the equation** as shown below.

2 OH^- + 2 I^- + 2 H^+ + OCl^- ----> I_2 + Cl^- + H_2O + 2 OH^-

12. Then, on that side of the equation which contains both (OH^-) and (H^+) ions, combine them to form H_2O. Note, combining the 2 OH^- with the 2 H^+ ions above gives 2 HOH or 2 H_2O molecules as written below.

$2\ H_2O + 2\ I^- + OCl^-$ ----> $I_2 + Cl^- + H_2O + 2\ OH^-$

13. Simplify the equation by subtracting out water molecules, to obtain the final, balanced equation.

$$
\begin{array}{l}
2\ H_2O\ +\ 2I^-\ +\ OCl^-\ \text{---->}\ I_2\ +\ Cl^-\ +\ H_2O\ +\ 2\ OH^- \\
-\ \mathbf{H_2O}\qquad\qquad\qquad\qquad\qquad\qquad -\ \mathbf{H_2O} \\
\hline
H_2O\ +\ 2I^-\ +\ OCl^-\ \text{---->}\ I_2\ +\ Cl^-\ +\ 2\ OH^-
\end{array}
$$

Note that both the atoms and charges are equal on both sides of the equation, and the presence of hydroxide ions (OH^-) indicates that the reaction occurs in basic solution.

Everyday Examples

Combustion of Fuels

The combustion or the burning of fuels, is perhaps the most common and obvious example of oxidation and reduction. Combustion is also that process which converts the potential energy of fuels into kinetic energy (heat and light). Most fuels (gasoline, diesel oil, propane, etc.) are compounds comprised primarily of carbon and hydrogen. These hydrocarbons represent an excellent source of potential energy, which is released as heat during the combustion process. A common example is the oxidation of propane, the fuel used for gas ranges:

$C_3H_8 + 5\ O_2$ -----> $3\ H_2O + CO_2$ + Heat

As propane burns in air, its carbon atoms are oxidized when they combine with oxygen to form carbon dioxide. In turn, molecular oxygen is reduced by the hydrogen atoms, forming water. The heat produced can be used directly such as in the cooking of foods or to cause the expansion of the gaseous products produced to perform mechanical work such as in an internal combustion or steam engine.

Many other substances besides hydrocarbons can be used as fuels. For example, the alcohols, such as methanol (CH_3OH) and ethanol (CH_3CH_2OH) are often used in racing cars. Ethanol mixed with gasoline, called gasohol , is currently being explored as a substitute for gasoline. Among the simplest fuels is molecular hydrogen (H_2) which readily reacts with oxygen forming water as shown:

$2\ H_2 + O_2$ ------> $2\ H_2O$ + Energy

The simplicity and "nonpolluting" aspect of this oxidation-reduction reaction, the amount of energy produced, and the relative abundance of both hydrogen and oxygen in our environment, makes hydrogen a very attractive alternative fuel source. Research efforts are currently focused on further developing the technology to broaden its use as a source of energy.

Corrosion

Millions of dollars are lost each year because of corrosion. Much of this loss is due to the corrosion of iron and steel, although many other metals may corrode as well. The problem with iron as well as many other metals is that the oxide formed by oxidation does not firmly adhere to the surface of the metal and flakes off easily causing "pitting". Extensive pitting eventually causes structural weakness and disintegration of the metal. (It should be noted, however, that certain metals such as aluminum, form a very tough oxide coating which strongly bonds to the surface of the metal preventing the surface from further exposure to oxygen and corrosion).

Corrosion occurs in the presence of moisture. For example when iron is exposed to moist air, it reacts with oxygen to form rust,

$$Fe_2O_3 \cdot X\,H_2O$$

The amount of water complexed with the iron (III) oxide (ferric oxide) varies as indicated by the letter "X". The amount of water present also determines the color of rust, which may vary from black to yellow to orange brown. The formation of rust is a very complex process which is thought to begin with the oxidation of iron to ferrous (iron "+2") ions.

$$Fe \text{ -------> } Fe^{+2} + 2\,e^-$$

Both water and oxygen are required for the next sequence of reactions. The iron (+2) ions are further oxidized to form ferric ions (iron "+3") ions.

$$Fe^{+2} \text{ ------------> } Fe^{+3} + 1\,e^-$$

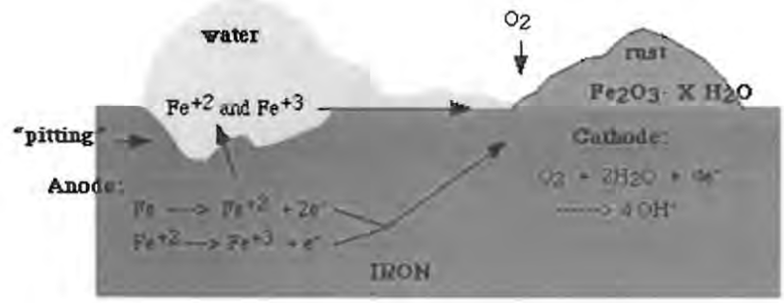
The electrons provided from both oxidation steps are used to reduce oxygen as shown.

$$O_2\,(g) + 2\,H_2O + 4e^- \text{ -----> } 4\,OH^-$$

The ferric ions then combine with oxygen to form ferric oxide [iron (III) oxide] which is then hydrated with varying amounts of water. The overall equation for the rust formation may be written as :

$$4\,Fe^{+2}(aq) + O_2\,(g) + [4 + 2\,X\,H_2O\,(l)] \text{ -----> } \underbrace{2\,Fe_2O_3 \cdot X\,H_2O\,(s)}_{\text{"rust"}} + 8H^+\,(aq)$$

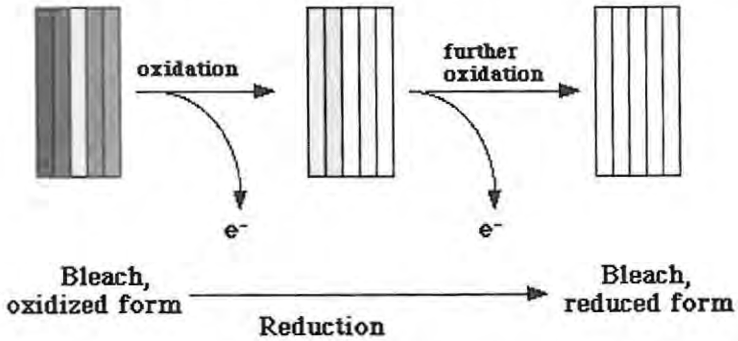
The formation of rust can occur at some distance away from the actual pitting or erosion of iron as illustrated below. This is possible because the electrons produced via the initial oxidation of iron can be conducted through the metal and the iron ions can diffuse through the water layer to another point on the metal surface where oxygen is available. This process results in an electrochemical cell in which iron serves as the anode, oxygen gas as the cathode, and the aqueous solution of ions serving as a "salt bridge" as shown below.



The involvement of water accounts for the fact that rusting occurs much more rapidly in moist conditions as compared to a dry environment such as a desert. Many other factors affect the rate of corrosion. For example the presence of salt greatly enhances the rusting of metals. This is due to the fact that the dissolved salt increases the conductivity of the aqueous solution formed at the surface of the metal and enhances the rate of electrochemical corrosion. This is one reason why iron or steel tend to corrode much more quickly when exposed to salt (such as that used to melt snow or ice on roads) or moist salty air near the ocean.

Bleaching Agents

Bleaching agents are compounds, which are used to remove color from substances such as textiles. In earlier times textiles were bleached by exposure to the sun and air. Today most commercial bleaches are oxidizing agents, such as sodium hypochlorite (NaOCl) or hydrogen peroxide (H_2O_2), which are quite effective in "decolorizing" substances via oxidation. The action of these bleaches can be illustrated in the following simplified way:



Recall that an oxidizing agent is any substance, which causes another substance to lose one or more electrons. The decolorizing action of bleaches is due in part to their ability to remove these electrons, which are activated by visible light to produce the various colors. The hypochlorite ion (OCl^-), found in many commercial preparations, is reduced to chloride ions and hydroxide ions forming a basic solution as it accepts electrons from the colored material as shown below.

$OCl^- + 2e^- + HOH \text{--------}> Cl^- + 2\ OH^-$

Bleaches are often combined with "optical brighteners". These compounds are quite different from bleaches. They are capable of absorbing wavelengths of ultraviolet light invisible to the human eye, and converting these wavelengths to blue or blue-green light. The blue or blue-green light is then reflected by the substance making the fabric appear much "whiter and brighter" as more visible light is seen by the eye.

Photosynthesis

An example of naturally occurring biological oxidation-reduction reactions is the process of photosynthesis. It is a very complex process carried out by green plants, blue-green algae, and certain bacteria. These organisms are able to harness the energy contained in sunlight, and via a series of oxidation-reduction reactions, produce oxygen and sugar, as well as other compounds which may be utilized for energy as well as the synthesis of other compounds. The overall equation for the photosynthetic process may be expressed as:

$$6\,CO_2 + 6H_2O \text{ --------> } \underset{\text{(glucose)}}{C_6H_{12}O_6} + 6\,O_2$$

The equation is the net result of two processes. One process involves the splitting of water. This process is really an oxidative process that requires light, and is often referred to as the **"light reaction"**. This reaction may be written as:

$$12\,H_2O \xrightarrow[\text{light or radiant energy}]{} 6\,O_2 + 24\,H^+ + 24e^-$$

The oxidation of water is accompanied by a reduction reaction resulting in the formation of a compound, called nicotinamide adenine dinucleotide phosphate (NADPH). This reaction is illustrated below:

$$\underset{\text{(oxidized form)}}{NADP^+} + H_20 \text{ -------> } \underset{\text{(reduced form)}}{NADPH} + H^+ + \underset{\text{(oxygen)}}{O}$$

This reaction is linked or coupled to yet another reaction resulting in the formation of a highly energetic compound, called adenosine triphosphate, (ATP). As this reaction involves the addition of a phosphate group (labeled, as P_i) to a compound called, adenosine diphosphate (ADP) during the **light reaction**, it is called **photophosphorylation**.

$$ADP + P_i \text{ ------------> } ATP$$

Think of the **light reaction**, as a process by which organisms "capture and store" radiant energy as they produce oxygen gas. This energy is stored in the form of chemical bonds of compounds such as NADPH and ATP.

The energy contained in both NADPH and ATP is then used to reduce carbon dioxide to glucose, a type of sugar ($C_6H_{12}O_6$). This reaction, shown below, does not require light, and it is often referred to as the "**dark reaction**".

$6\,CO_2 + 24\,H^+ + 24\,e^- \text{------>} C_6H_{12}O_6 + 6\,H_2O$

The chemical bonds present in glucose also contain a considerable amount of potential energy. This stored energy is released whenever glucose is catabolised (broken down) to drive cellular processes. The carbon skeleton in glucose also serves as a source of carbon for the synthesis of other important biochemical compounds such as, lipids, amino acids, and nucleic acids.

In simplest terms, the process of photosynthesis can be viewed as one-half of the carbon cycle. In this half, energy from the sun is captured and transformed into nutrients, which can be utilized by higher organisms in the food chain. The release of this energy during the metabolic re-conversion of glucose to water and carbon dioxide represents the second half of the carbon cycle and it may be referred to as catabolism or "oxidative processes".

Metabolism

Metabolism is a general term used to refer to all of the chemical reactions, which occur in a living system. Metabolism can be divided into two parts; anabolism, or reactions involving the synthesis of compounds; and catabolism, or reactions involving the breakdown of compounds.

In terms of oxidation-reduction principles, anabolic reactions are primarily characterized by reduction reactions, such as the **dark reaction** in photosynthesis where carbon dioxide is reduced to form glucose. Catabolic reactions are primarily oxidation reactions. Although catabolism involves many separate reactions, an example of such as process can be described by the oxidation of glucose as shown below. Note that this equation is the reverse of the photosynthetic equation.

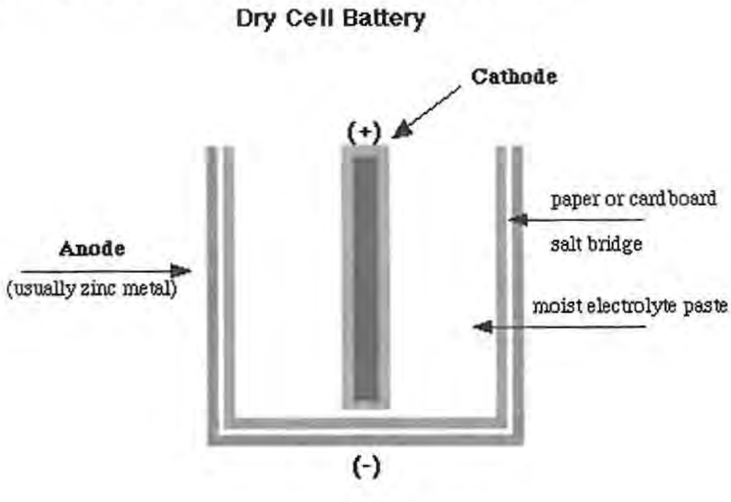
$C_6H_{12}O_6 + 6\,O_2 \text{---------->} 6\,CO_2 + 6\,H_2O + \text{Energy}$

Note also, that in this reaction, the carbon atoms in glucose are oxidized, undergoing an increase in oxidation state (each carbon loses 2 electrons) as they are converted to carbon dioxide. At the same time, each oxygen atom is reduced by gaining 2 electrons when it is converted to water. Part of the energy is released as heat and the remainder is stored in the chemical bonds of "energetic" compounds such as adenosine triphosphate (ATP) and nicotinamide adenine dinucleotide (NADH).

Catabolic reactions can be divided into many different groups of reactions called, catabolic pathways. In these pathways (referred to as Glycolysis, the Citric Acid Cycle, and Electron Transport) the carbon atoms are slowly oxidized by a series of reactions which gradually modify the carbon skeleton of the compound as well as the oxidation state of carbon. Coupled to these reactions are other reversible oxidation-reduction reactions designed to capture the energy released and temporarily store it within the chemical bonds of compounds called adenosine triphosphate (ATP) and nicotamide dinucleotide (NADH) . These compounds are then utilized to provide energy for driving the cellular machinery.

The "Dry-Cell" Battery

The most common type of battery used today is the "dry cell" battery. There are many different types of batteries ranging from the relatively large "flashlight" batteries to the minaturized versions used for wristwatches or calculators. Although they vary widely in composition and form, they all work on the sample principle. A "dry-cell" battery is essentially comprised of a metal electrode or graphite rod (elemental carbon) surrounded by a moist electrolyte paste enclosed in a metal cylinder as shown below.



In the most common type of dry cell battery, the cathode is composed of a form of elemental carbon called **graphite**, which serves as a solid support for the reduction half-reaction. In an acidic dry cell, the reduction reaction occurs within the moist paste comprised of ammonium chloride (NH_4Cl) and manganese dioxide (MnO_2):

$2\,NH_4^+ + 2\,MnO_2 + 2e^-$ ------> $Mn_2O_3 + 2\,NH_3 + H_2O$

A thin zinc cylinder serves as the anode and it undergoes oxidation:

$Zn\,(s)$ ---------------> $Zn^{+2} + 2e^-$

This dry cell "couple" produces about 1.5 volts. (These "dry cells" can also be linked in series to boost the voltage produced). In the **alkaline** version or **"alkaline battery"**, the ammonium chloride is replaced by KOH or NaOH and the half-cell reactions are:

$Zn + 2\,OH^-$ -------> $ZnO + H_2O + 2e^-$

$2\,MnO_2 + 2e^- + H_2O$ -------> $Mn_2O_3 + 2\,OH^-$

The alkaline dry cell lasts much longer as the zinc anode corrodes less rapidly under basic conditons than under acidic conditions.

Other types of dry cell batteries are the **silver battery** in which silver metal serves as an inert cathode to support the reduction of silver oxide (Ag_2O) and the oxidation of zinc (anode) in a basic medium. The type of battery commonly used for calculators is the **mercury** cell. In this type of battery, HgO serves as the oxidizing agent (cathode) in a basic medium, while zinc metal serves as the anode. Another type of battery is the **nickel/cadmium** battery, in which cadmium metal serves as the anode and nickel oxide serves as the cathode in an alkaline medium. Unlike the other types of dry cells described above, the nickel/cadmium cell can be recharged like the lead-acid battery.

Basic Applications

Exercise 1 Determining Oxidation States

Determine the oxidation state of metals in the following compounds. Note, for the transition metals which exhibit multiple oxidation states, you must first find the charge of the non-metal ions. "Oxidation-Reduction Reactions: A Basic Model".

For example: for $FeCl_2$, the answer is **Fe+2**

(1) Cu_2O

(2) Cr_2O_3

(3) MnO_2

(4) Al_2S_3

EXERCISE 2: Single Displacement Reactions

Given the reactions below, answer the following questions:

(1) $2Fe + 6HCl \dashrightarrow 2FeCl_3 + 3H_2$

List the symbol of the element being oxidized:

How many electrons are lost by each oxidised atom?

(2) $Cu + 2AgNO_3 \dashrightarrow Cu(NO_3)_2 + 2Ag$

List the symbol of the element being reduced:

How many electrons are gained by each reduced atom?

(3) $Mg + 2H_2O \dashrightarrow Mg(OH)_2 + H_2$

List the symbol of the element being reduced:

How many electrons are lost by the oxidised atom?

EXERCISE 3: Balancing Redox Equations

(1) Balance the following reaction assuming it occurs in an acidic medium, and enter the proper coefficients in the blank spaces.

$MnO_4^{-1} + H_2O_2 \dashrightarrow Mn^{+2} + O_2$

(2) Balance the following reaction assuming it occurs in an acidic medium, and enter the proper coefficients in the blank spaces.

$HNO_2 + I^{-1} \dashrightarrow NO + I_2$

(3) Balance the following reaction assuming it occurs in an basic medium, and enter the proper coefficients in the blank spaces.

$S^{-2} + I_2 \dashrightarrow SO_4^{-2} + I^{-1}$

(4) Balance the following reaction assuming it occurs in an basic medium, and enter the proper coefficients in the blank spaces.

$CN^{-1} + MnO_4^{-1} \dashrightarrow CNO^{-1} + MnO_2$

References

Blignaut, E., de Villiers, J., Finnemore, D., Gibbon, D., Hicks, D., Jordaan, F. and Marias, P. (1988). *Modular teacher's guide for the teaching of senior physical science (2).* Stellenbosch: The Institute for Mathematics and Science Teaching, University of Stellenbosch.

http://library.kcc.hawaii.edu/external/chemistry

Appendix D

INTERVENTION ACTIVITIES AND WORKSHEET

These activities aim at developing learners' conceptual understanding of oxidation and reduction reactions. Knowledge of oxidation and reduction (redox) processes is essential if we are to understand many of the reactions we have come to accept as part of our everyday lives. To give a few examples, batteries, photography, the use of fuel and life process such as photosynthesis and respiration are oxidation and reduction reactions.

Activity 1

Let us refresh our memory with one of the previous activity we performed during the pre-intervention session. Read carefully and follow the instructions outlined.

Description: Investigation the reducing ability of a few metals in terms of metal displacement reactions. Also arranging these metals in a reactivity sequence.

Equipment and Chemicals

Beakers, stirring rod, microchem kit, zinc metal, iron metal, magnesium ribbon, copper metal, aluminium sulphate solution, iron (II) sulphate solution, Copper (II) sulphate solution, zinc sulphate solution, aluminium rod and copper rod.

Method

- Pour about 5ml of each of the solutions provided in a test tube.
- Place a clean piece of the zinc metal into each of the solutions.
- Wait for 2 minutes
- Record any observations.
- Repeat for the other metals (Mg, Fe, and Cu).

Complete the table below: **Table 3**

Metal	Sulphate solutions	Precipitate	Oxidised substance	Reduced substance
Zinc	Iron (II)			
Iron	Copper (II)			
Magnesium	Aluminium			
Copper	Zinc			

1. Represent the reactions in each well by a half-reactions and give the net reaction.

....

....

....

....

2. Arrange the metals in a reactivity sequence: the most reactive metal at the top of the series will be the one that can displace all the metals below itself.

....

End of Activity 1

Activity 2

Description: Investigating the oxidation of one halogen by another

Equipment and Chemicals

Microchem kit, glass rod, chlorine water, bromine water and potassium iodide

Method

Prepare chlorine water by bubbling chlorine gas through water. Also prepare bromine water by shaking up a few drops of bromine in water. Prepare dilute solution of potassium iodide.

- In the comboplate combine equal volumes of:
    1. Chlorine water and bromine water
    2. Chlorine water and potassium iodide solution
    3. Bromine water and potassium iodide solution.

Complete the table below: **Table 4**

	Solution	Observation
1	Chlorine water + Bromine water	
2	Chlorine water + Potassium iodide	
3	Bromine water + Potassium iodide	

Tabulate your results and draw conclusions: **Table 5**

	Solutions	**Colour Change**
1	Bromide water + Chlorine water	
2	Potassium iodide + Chloride water	
3	Potassium iodide + bromine water	

Explain why these colour changes occur and give the half-reactions and the net redox reaction in each case.

....

....

....

....

....

....

....

....

End of Activity 2

Thanks for your participation and input

Billey Addam

Appendix E

TRANSCRIBED AUDIO-VISUAL OBSERVATION WORKSHOP

The Audio-visual observation workshop took place on the 24th of September 2003 at my school at 10:00am. All the learners involved in the research were present and worked in their groups.

Introduction

In a school like this where we teach science without laboratory, equipment and no flow of water, performing science experiments become a very difficult task for science teachers. However, under these striving circumstances, we do our best to provide learners and equip them with adequate scientific knowledge and practical activities to face the realities of science in the real-life situation.

Instruction

This workshop has to do with evoking learners, knowledge on redox reactions by means of 'word association exercise'. Interact in your groups and brainstorm one another on words that you can classify under (i) oxidation (ii) reduction and (iii) oxidation and reduction.

Write your findings on the newsprint provide with the khoki pen on your table. Select a representative for the group who will present your finding during a plenary session. You may spend 1hour to write your findings and 6minutes for presentation and 2minute for questions.

Pause for one hour as the learners brainstorm and organise their discussion.

Reporting of findings

Group A

The presenter look quite scared and unstable, however did complete her task.

Oxidation

- Loss of electrons by a substance which includes: ions, molecules and atoms
- Traditionally, it is the addition of oxygen or removal of hydrogen
- When it losses electron the name of the ion is formed. Example when copper losses two electrons, it becomes copper ion, magnesium will become magnesium ion.

Reduction

- Removal of oxygen or the addition of hydrogen
- When it gains electrons the name of the ion is formed. Example chlorine gains one electron and become the chloride ion, oxygen gains two electrons and become oxide ion, sulphur gains two electrons and become the sulphide ion.

Redox

- Red = reduction – removal of oxygen
- Ox = oxidation – addition of oxygen
- Respiration – addition of oxygen and removal of oxygen in carbon dioxide
- Photosynthesis – removal of oxygen and addition of oxygen in carbon dioxide.

Pr_1 Any questions?

Class No questions.

Group B

Pr_2 Good morning every one

Class Good morning

Oxidation	Reduction
• Addition of oxygen • Loss of electrons • Reducing agent • Half reaction • Removal of hydrogen • Oxidation half cell • Oxidation number	• Removal of oxygen • Gain of electron • Oxidising agent • Reduction half cell • Addition of hydrogen • Oxidation number

Redox

- Nett reaction
- Natural occurring activities using the principle such as photosynthesis, respiration and environmental situations like rust.

Pr_2 Any questions

Class No questions.

Group C

Pr_3 Good morning class!!

Class Good morning, Sir

Oxidation	Reduction
• Loss of electrons • Removal of hydrogen • Positive ions • Reducing agent • Increase in oxidation number	• Gain of electrons • Addition of hydrogen • Negative or less positive ions • Oxidising agent • Decrease in oxidation number

- Photosynthesis – during the photosynthesis – gain in energy – when the chlorophyll in the plant absorbs radiant energy from the sun, the water in the chlorophyll splits. The hydrogen goes into the NDP and the oxygen into the atmosphere. I can say there is removal of oxygen and removal of hydrogen.
- Respiration – is part of redox because it is the process whereby we use oxygen from the atmosphere and give off oxygen in carbon dioxide.
- Rusting is also a redox process.

Pr_3 Any questions?

L_1 I have a question for you. Is it true that during respiration oxygen is released?

Pr Yes. In fact it is not released as molecular oxygen but in the combined form with carbon.

L_2 What is the relationship between respiration and photosynthesis?

Pr_3 As I have illustrated the two processes are directly opposite.

Pr_3 Any more questions?

Class No thanks.

Group D

Pr4 Hi class

Class Hallo there

Oxidation	Reduction	Redox
• Oxidised • Loss of electrons • Addition of oxygen • Removal of hydrogen • Reducing agent • Oxidation half cell • Oxidation half reaction	• Reduced • Gain of electrons • Removal of oxygen • Addition of hydrogen • Oxidising agent • Reduction half cell • Reducing half reaction	• Net redox reaction • Simultaneous reaction • Oxidation and reduction • Energy transferred • Rust formation • Combustion • Metabolism

Pr4 Any questions?

L7 You have explained very well to my understanding the concept of oxidation and reduction. Now under oxidation, what is the chemical reaction of addition of oxygen and under reduction, what is the chemical reaction of the removal of oxygen? (requested a reaction illustrating the addition and removal of oxygen as a redox principle)

Pr4 (long pause…scratch the head…fell into a deep thinking and put up a smile then looked at his group and suddenly a member of the group [PrD] came to the front to explain).

PrD Let us consider the reaction between carbon and oxygen. Carbon reacts with to form carbon dioxide.

$$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$$

Here, oxygen has been added to carbon - oxidation

Again, when magnesium reacts with steam ($H_2O_{(g)}$) the magnesium removes oxygen from the steam forming magnesium oxide and hydrogen gas evolved.

$$Mg_{(s)} + H_2O_{(g)} \rightarrow MgO_{(s)} + H_{2(g)} \quad \text{- (redox)}$$

The steam has been reduced to hydrogen by the removal of oxygen by magnesium.

L7 Thanks, I am satisfied.

PrD Any other questions?

Class No

Group E

Pr_5 Good morning all

Class Good morning, Sir

Oxidation	Reduction	Redox
• Loss of electrons • *pause a while* • Reducing agent because it helps another substance to be reduced and ending up being oxidised • Addition of oxygen • Removal of hydrogen • Increase in oxidation number	• Gain of electrons • Oxidising agent because it helps another substance to be oxidised and itself reduced • Removal of oxygen because if you remove oxygen from that substance, it becomes reduced • Addition of hydrogen • Decrease in oxidation number	• Rusting of iron • Photosynthesis • Respiration • Combustion • Car battery • Net redox reaction • Oxidant /reductant • Loss/gain of electrons • Half reaction • Cell reactions

Pr_5 Any questions?

L When you put iron nail in water, bubbles are produced signifying that a gas is being released. Is it oxygen gas? Can this gas be collected? If so how?

Pr_5 I don't think that the bubbles you observed was oxygen gas, rather it could be hydrogen.

L Why?

Pr_5 Pause…Sheeee…well…okay…yes…I think the water may be slight acidic therefore, hydrogen gas might have been released (remember grade 9 experiment on reactions of acids with some metals). Secondly the iron nail rusts due to its reaction with oxygen and the water.

L How would you collect the gas?

L(E) : (*A learner from group E responded*). Yes… by connecting a delivery tube and collect over water (preparation of hydrogen and oxygen – grade 9 experiment).

R A good demonstration of conceptual development. However, we need to do further investigation on this later.

Pr_5 Any more questions?

Class No.

Appendix F

TRANSCRIBED INTERVIEW

The interview was conducted on the 4th of October 2003 as the last technique for data collection. There were three focus questions with follow-up questions depending on the response from the interviewee. The interview session, which started at 9:00am ended at 10:30am.

The focus questions were:

- Can you explain what you understand about oxidation – reduction reactions?
- Explain why you think it is important to paint corrugated iron roofing sheets or iron metal gates?
- How do you find the approach adopted in teaching this topic? Has it helped you to understand concepts better? How and why?

The interview however started with familiarising questions, which include:

- Do you like your school? Why?
- Do you like science and why?
- Which topic in science do you like most and why?

Below I present samples of the interview session.

Interview with learner (L_1)

I Do you like your school? Why?

L_1 Yes, because it is near my home so I can walk to school.

I Which topic in science happens to be your best in the previous year?

L_1 Acids and Bases.

I Why?

L_1 Because some other acids and bases are used regularly at home and others are used industrially.

I So you know the difference between the acids, which are used at home, and the ones, which are used in the industry.

L_1 Yes

I Can you give an example of home acids and industrial acids?

L_1 For example, home acids, vinegar, and industrial acid hydrochloric acid and bases; soap used at home and sodium hydroxide used in the industry.

I What made you to have special interest in science?

L_1 Because there are some things that I do at home and they are related to that I do in class that are related to science.

I Do you mean to say that the knowledge you have on science is from the home to school and from school to the house?

L_1 Yes, because when I learn something at school I always see how I can use it at home and also at home if something happens I think of it and find out more on it when I go to school.

I Seemingly, you apply science even at home and you apply science from home at school.

L_1 Yes.

I So you can easily relate activities in the house and the knowledge you acquire from the classroom?

L_1 Yes.

I Now we have studied oxidation – reduction reaction reactions in grade 11.

L_1 Yes

I Have you ever interacted with this topic anywhere in the previous grade?

L_1 Yes, but briefly when we studied "electrolysis" but I did not understand anything about it.

I Now that we have studied it into detail, do you understand it well?

L_1 Yes, and I can teach it to any one who needs me to do so.

I Give a brief background explanation of oxidation and reduction.

L_1 Traditional concept, oxidation is the removal of hydrogen or the addition of oxygen and reduction is the addition of hydrogen or the removal of oxygen. The new definition, oxidation is the loss of electrons or the increase in oxidation number and reduction is the gain of electrons or the decrease in oxidation number.

I Explain the oxidation number concept a little further

L_1 For example, if I have copper with a +2 and after losing one electron to another substance, it will become copper with a +3 and this is an increase in oxidation number and the substance that gains the electron becomes more negative or less positive therefore it has decrease in oxidation number.

I We have performed an activity to determine the reactivity series. Apply your knowledge of the reactivity series to explain why certain metal salt solution cannot be stored in certain metal containers.

L_1 Sir, the metal container may dissolve in the metal salt solution if the metal container is more reactive the metal of the salt.

I Can you briefly relate redox to the environment or a biological system?

L_1 Yes, Environmentally, I can relate redox to rusting of iron ... pause ... and photosynthesis that happen freely in green plants or algae or some bacteria and respiration that happens to me. I can relate that oxidation – reduction reaction because I can inhale oxygen and exhale carbon dioxide whereby oxygen is added which is oxidation and oxygen is remove which is also reduction. Then on rusting of iron, oxygen reacts with iron and forming iron oxide whereby iron is oxidised by the addition of oxygen.

I Explain why it is important to paint metal gates or iron roofing sheets or even spray cars?

L_1 With the iron roofing sheets, the oxygen in the water and atmosphere reacts with the iron then the iron rust that an addition of oxygen to the iron metal and also an increase in oxidation number that is from =2 to +3.

I Do you have an idea about how the car battery operates?

L_1 Yes

I Can you explain?

L_1 Yes but not today

I Do you have any comment to make?

L_1 I am out of words.

I Thanks very much for your contribution.

Interview with learner (L_2)

I L_2 welcome to this interview session, be very free and relax. Respond to the questions as best as you can.

L_2 Okay Sir,

I Do you like your school and why?

L_2 I like here at the same time dislike it. Because ... Okay ...Pause ...I like it because it has good teachers ...Okay...What else..pause... I dislike it because when we do experiments, there are no laboratories and you have to collect water from a far place to wash the items.

I What was your best topic in science in grade10?

L_2 Shoo! ... Okay ...long pause ... acids and bases.

I Why do you like this topic?

L_2 Laugh .... Long pause ... I don't have a reason

I Can you explain what you understand about redox reactions?

L_2 'Red' stands for reduction and 'ox' stands for oxidation. Also oxidation is the loss of electron and reduction the gain of electrons. Again oxidation is the loss of hydrogen and reduction the gain of hydrogen. And oxidising agent is that substance that helps another substance to be oxidised and get reduced at the end and a reducing agent is that substance that helps another substance to be reduced and get oxidised itself.

I We have performed an activity to determine the reactivity series. Apply your knowledge of the reactivity series to explain why certain metal salt solution cannot be stored in certain metal containers.

L_2 The position of the metal of the container and the metal of the salt in the reactivity series counts very much. If the metal of the container is more reactive than the metal of the salt solution, the metal of the container will be oxidised and the metal of the salt will be reduced. However it the opposite is the case then that container is good. For example, storing copper sulphate solution in an iron container will not be okay since iron is more reactive than copper, so the iron will displace copper ions to form copper metal and the iron container will dissolve in the solution while copper deposits.

I Can you explain some process that occur in the environment that are redox reactions?

L_2 Okay ... photosynthesis plants does need oxygen. When you pour water on the plants they take hydrogen and breathe out oxygen and also take in carbon dioxide. And respiration ... and ... shee ...shee ...(very uncomfortable full of body movement)

I Does the environmental illustrations assist you to understand redox reactions?

L_2 Yes I think so because I apply the science I learn at school in the home.

I Why is it important that we paint cars, iron metal gates and iron roofing sheets?

L_2 Well ... Okay ... Hmm ...(shaking the head for a while) ... a few seconds pause ...you see when we do not paint the roof it will rust because oxygen in the air and water also in the atmosphere will react with the iron so the iron gets oxidised. The same is the iron gates and cars.

I Is the approach adopted in teaching this unit different from the one you are used to?

L_2 Yes

I How does it influence your understanding?

L_2 In fact ... Okay ... it has made science real to me. I can now see that science is all around me. I now like science more than all the other subjects.

I Do you have anything to say?

L_2 Sir, I am shy that is why I could not answer the questions well. Also I like your teaching only that you like using big English.

I Thanks very much. You are a joy to have in class.

Interview with learner 3 (L_3)

I Good morning and how are you?

L_3 Fine morning. I am very well. Thank you.

I What do you do on weekends?

L_3 Nothing special

I Which grade 11 topic in science do you find difficult?

L_3 So far there is none but I struggle to understand redox very well.

I What are the few things you can explain regarding redox?

L_3 Well ... pause ...I understand that redox stands for reduction and oxidation reactions. The 'red' for reduction and the 'ox' for oxidation. And oxidation is the loss of electrons by a substance and reduction is the gain of electrons by a substance. So when a substance gains electrons that means it is reduced therefore it is an oxidising agent and if a substance losses electrons it means it has been oxidised then it is a reducing agent.

I This is quite a good explanation. Can you teach this topic to the grade 10 class?

L_3 Yes because though I struggled to understand it now I do understand it very well and can teach it to even the grade 12 class.

I What helped you to understand it they way you are saying?

L_3 ... Pause ...Yes ... the way you teach and the examples you used. For example, you always relate your teaching to real-life things that we see around us. Sometimes you make us find out these things by ourselves. In fact I like the way you teach maths and science but especially science. I want to be a doctor and if you should teach me science in grade 12 I will pass well and move forward.

I Thanks for the complement. Anyway ... can you relate your knowledge of redox to explain why we paint iron-roofing sheets?

L_3 Yes … Hmm … I can talk about green plants. Photosynthesis and respiration. We as human when we breathe air, we breathe in oxygen and breathe out carbon dioxide. But in plants it is the opposite. So I can say that when a plant losses the oxygen, it is reduction but there is oxygen in the carbon dioxide they take in so this is also oxidation. This means that redox process is taking place. The same is for respiration.

I We have performed an activity to determine the reactivity series. Apply your knowledge of the reactivity series to explain why certain metal salt solution cannot be stored in certain metal containers.

L_3 Okay there may be or not a reaction depending on the type of metal solution and the container.

I Is it important to paint iron gates?

L_3 Yes

I Why?

L_3 Fine … pause for 1 minute … the iron metal will be oxidised by the atmospheric oxygen and the water vapour so when you paint the gate the oxygen will not have the chance to oxidise the iron gate.

I Thanks very much. You have been very helpful.

L_3 You are welcome.

Interview with learner 4 (L_4)

I Good morning

L_4 Good morning Sir

I You looking ready for the interview

L_4 Yes Sir.

I You seem to like the school very much

L_4 That is not true or may be … I don't know

I What would you like to do in future?

L_4 I want to be a doctor

I That means you like Biology and Science?

L_4 I think so

I One of the topics we studied this was redox. Explain to me what you understand by redox reactions

L_4 Okay, to start with I will define redox. Redox simply means reduction (red) and oxidation (ox). The addition of oxygen and removal of hydrogen were all the traditional definitions of oxidation. On the other hand, the removal of oxygen and the addition of hydrogen were also the traditional definition of reduction. The modern concept defines oxidation as the loss of electrons/ the increase in oxidation number. Similarly, reduction is define as the decrease in oxidation number / gain of electrons. The substance that gains electron is the oxidising agent and the one that losses the electron is the reducing agent.

I We have performed an activity to determine the reactivity series. Apply your knowledge of the reactivity series to explain why certain metal salt solution cannot be stored in certain metal containers.

L_4 Okay ...pause... I have the idea but I don't know how to explain it.

I Can you relate redox to real-life situation?

L_4 Yes, for example photosynthesis. During photosynthesis, green plants absorb carbon dioxide and give off oxygen therefore, it is a practical unit relating to all spheres of real-life and more so to the environment (I mean the topic redox reactions).

I Can you talk about why the need to paint roofing sheets made of iron?

L_4 Well, you took us round at the beginning of the lesson to find out the problem with iron roofing sheets and compare those painted with those not painted. It became clear to me that the unpainted sheets look very dull and some rusted. This to me in scientific term means that a reaction has occurred. I can say that since rust is a redox reaction. The painting of the sheet will prevent redox reaction from taking place.

I How do you find the approach used in teaching this topic?

L_4 You have tried .. Well .. you are trying. This has been my best topic well understood and can teach it to any one. But Sir, you talk too fast. Initially I cannot hear you properly but as they went on it became fine. I like your stories when teaching which help me to understand because when I get home and I think about your stories it helps me to understand ... laugh .. that is all.

I It is nice to have you around and thanks very much.

L_4 The pleasure is mine.

Interview with learner (L_5)

I	Welcome
L_5	Thank you, Sir
I	You look happy in this school. Why ?
L_5	I really like this school because the teachers are very friendly and hard working and it is nearer my home.
I	Mention a topic you loved most in your previous grade.
L_5	Acids and Bases and also Electricity
I	What made you like these topics?
L_5	Pause .... Hmm ... Okay ...Ush ...(a lot of head and leg movement) ... I just enjoyed the topics.
I	Do you understand my teaching?
L_5	Yes
I	How?
L_5	Because you explain things very well to my understanding.
I	Redox was the last topic we studied before this interview. Can explain to me your understanding of this topic?
L_5	Oxidation ... pause ...it is the loss of electron addition of oxygen, removal of hydrogen or increase in oxidation number and reduction the gain of electrons removal of oxygen or the addition of hydrogen. The processes of rusting and photosynthesis are all redox process
I	Why do you think it is important to pain iron gates?
L_5	To prevent them from rusting.
I	Any comment from you?
L_5	Pause ... move the legs up and down .... No comment Sir.
I	Can you relate redox to any Biological system?
L_5	Yes, photosynthesis and respiration
I	Explain photosynthesis as a redox process.
L_5	Okay ...pause ...(scratch the hair, body, and play around with the arms and legs) ... pause ... okay .. It is a complex process but say green plants use carbon dioxide in the presence of sun energy to manufacture their food and give off oxygen. Here oxygen is taken in and given off so it is a redox process.
I	How do you find the interview?
L_5	Well it is okay but scary and the questions difficult.
I	Thanks very much. It is a pleasure talking with you.