UNIVERSITY OF CAPE COAST

IMPROVING CHEMISTRY STUDENTS' CONCEPTION OF REDOX REACTIONS USING THE PARTICIPATORY TEACHING AND LEARNING APPROACH

BY

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature: .... Date: 09/03/2017

Name: Kenneth Adu-Gyamfi

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

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ABSTRACT

The study was intended to design and develop the participatory teaching and learning approach (PTLA) to the teaching and learning of oxidation-reduction reactions. The research approach for the study was design-based research, using qualitative and quantitative methods. The design-based research approach consisted of four stages as preliminary, design and development, prototype, and systematic reflection and documentation stages. At the preliminary stage, six teachers and 213 third year students were sampled and at the prototype stage, 15 second year students were sampled. All samples were selected through stratified and simple random sampling procedures. At the preliminary stage, teachers were interviewed on teaching of and the third year students responded to diagnostic test and interviews on conception of oxidation-reduction reactions. The findings show that teachers used unstructured teaching strategies and students showed alternative conceptions and other conceptual difficulties in oxidation-reduction reactions. The PTLA was designed and developed by the researcher and validated by three experts at the design and development stage. At the prototype stage, the 15 students were taught using PTLA which helped improve their conception of oxidation-reduction reactions. It was therefore recommended that the leadership of the school in conjunction with Ghana Education Service should organise in-service training to train the school chemistry teachers on using PTLA in teaching chemical concepts.

KEY WORDS

Design-based research

Oxidation-reduction reactions

Participatory teaching and learning approach (PTLA)

Students

Teachers

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DEDICATION

To my family.

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CHAPTER ONE

INTRODUCTION

The chapter is the introduction to the study. It looks at the background to the study and the purpose for the conduct of the study. The study was guided by five research questions in the area of teaching and learning of oxidation-reduction reactions and they are presented in the chapter. The scope of the study and weakness associated with the methodology of the study are also presented and discussed in the chapter.

Background to the Study

The formation of new substances which are different from the starting substances is associated with chemical changes. The process through which new substances are formed as a result of chemical change is referred to as a chemical reaction. There are several types of chemical reactions and these can be classified in more than one way. In one class of chemical reactions, two or more chemical substances combine to form a single complex new substance; in another class, a single substance breaks down to form smaller new substances; also in some other class, an atom or atoms of one of the elements of a substance is displaced from its compound by another element; and in another case, two substances exchange bonds or ions to form new substances. There are other classes of chemical reactions where acid and base exchange H^+ and OH^- ions respective to form water and ionic salt; the structural arrangement of the substance is changed but its net atomic composition remains unchanged; water is involved; and oxidation numbers of atoms in the substance are changed (Ameyibor & Wiredu, 1993; Bodner & Pardue, 1995; Chang, 2003).

One of these classes of chemical reaction which has gained national and international consideration for student learning at the pre-university level is the one where the oxidation numbers of the atoms in substances are changed (Ministry of Education [MOE], 2010; Sixth Form at Brimsham Green [SFBG], 2012; The University of the State of New York [TUSNY], n.d.). This is oxidation-reduction reaction which is commonly referred to as redox reaction. TUSNY (n.d.) prepared a core document which is not a syllabus but a document from which high schools in the New York State could prepare school curriculum, instruction, and assessment. In this core document, oxidation-reduction reaction was outline as one of the major areas for consideration. SFBG (2012) used the sub-section 5.3 of Unit 3 to present content relating to oxidation-reduction in the area of equilibria.

High school chemistry students from countries such as Gambia, Ghana, and Nigeria are examined by the West African Examination Council (WAEC) using a certain designed syllabus. In the WAEC chemistry syllabus, oxidation-reduction reactions are considered as one of the important areas for member countries to focus on. In Ghana, from the WAEC syllabus, the planners of the senior high school (SHS) chemistry syllabus considered oxidation-reduction reactions as one of the important reactions for students to learn. The Section 5 of the second year outline of the Ghanaian chemistry syllabus has been assigned to the teaching of oxidation-reduction reactions (MOE, 2010; 2012).

In Ghana, there are two general objectives for the teaching and learning of oxidation-reduction reactions in the Chemistry Teaching Syllabus at the SHS level (MOE, 2010; 2012). These general objectives are the students will: "(1) understand the nature of oxidation-reduction reactions and apply its principles to electrochemical cells and (2) show awareness of corrosion as an oxidation-reduction process and its economic cost" (MOE, 2010, p. 40). The implication of the first general objective is that there is the need for students to conceptualise the meaning of oxidation-reduction reactions in order to apply their usage in everyday life such as its usage in electrochemical cells. To achieve these two general objectives, the Section 5 of the second year aspects of the chemistry syllabus is structured with six units sequenced as: "oxidation-reduction processes and oxidising-reducing agents; balancing of redox reactions; redox titrations; electrochemical cells; electrolytic cells; and corrosion of metals" (MOE, 2010, p. 40).

The history of oxidation-reduction reactions is an interesting one. It started with the phlogiston theory (where all materials that can burn were said to contain phlogiston) through to the Lewis concept of acids and bases (where atoms forming molecules were said to share electron pair). Osterlund and Ekborg (2009) identified from the literature that there are four different models for the teaching and learning of oxidation-reduction reactions in chemistry education. These models are oxygen model, which is loss of oxygen for reduction and gain of oxygen for oxidation; hydrogen model, which is gain of hydrogen for reduction and loss of hydrogen for oxidation; electron transfer model, which is gain of electrons for reduction and loss of electron for oxidation; and oxidation number model, which is decrease in oxidation number for reduction and increase in oxidation number for oxidation. These four models of oxidation-reduction reactions are currently being used by academic institutions for teaching the concept of oxidation-reduction reactions. Chang (2003) asserted that the concept of oxidation-reduction reactions was basically used to denote reactions involving oxygen but the concept has a much broader meaning to chemists in today's world. This is why academic institutions world over present the concept of oxidation-reduction reactions using the four models instead of the use of only the oxygen model.

The Unit 1 of the Section 5 of the second year aspects of the Ghanaian chemistry syllabus is where the meaning of the chemical concept of oxidation-reduction reactions is taught and learnt. It could be seen from the chemistry syllabus that the concept of oxidation-reduction reactions is treated as addition and removal of hydrogen and oxygen; loss and gain of electrons; and change in oxidation state. The planners of the syllabus have then identified the four models of oxidation-reduction reactions and therefore require that students are given the opportunity to learn the four models at approximately the same time. However, when it comes to the evaluation aspects of the syllabus, the planners of the syllabus only asked that students "define oxidation and reduction in terms of electron transfer and oxidation numbers" (MOE, 2010, p. 40). It could be inferred from this evaluation exercise that the planners of the syllabus have realised the challenges the four models posed to students. It could also be inferred that the planners of the syllabus appreciated that the electron transfer and oxidation number models can just help students to make meaning of the concept of oxidation-reduction reactions. It could further be that for want of space, the planners of the syllabus limited the number of evaluation questions raised.

It must be stressed that oxidation-reduction reactions are the basic source of the earth's energy (Wilbraham, Staley, Simpson, & Matta, 1987) and are commonly experienced from burning of fossil fuels to the action of household bleach. For instance, a lot of metallic and non-metallic elements are extracted from the ores by the process of oxidation-reduction reactions (Chang, 2003); such extraction includes production of iron from blast furnaces and electrolysis of aluminium oxide melt for aluminium production. The rest are production of electrical energy from batteries and accumulators such as the regular galvanic cell battery, which make use of two dissimilar metals (Hunt, Sorey, Balandova, & Palmquist, 2010); cell respiration (Wilbraham et al., 1987); and fluoridation, which is addition of fluorine in tooth paste and table salt (Mpofu, 2006). This is indeed an important area for researchers to investigate.

Various approaches to teaching have been observed to have effects on students' performance in oxidation-reduction reactions (Anderson, Mitchell, & Osgood, 2005; Hunt et al., 2010; Majerich & Schmuckler, 2008; Own, 2005; Purtadi & Sari, n.d.; Udo, 2011). In comparing conventional learning to cooperative learning in oxidation-reduction reaction, Anderson et al. (2005) found out that students' performance in oxidation-reduction reaction was enhanced by the cooperative learning approach adopted by their study. Hunt et al. (2010)

observed that in using hands-on instruction, where students connected three dissimilar metals to a single lemon, the students conceptualised that a reaction involving electron transfer is oxidation-reduction reaction. During the hands-on activity, a positive voltage on digital multimeter shows reduction and a negative voltage shows oxidation. Thus, students understood that each of the voltages measured showed that the metal was gaining or losing electrons.

Own (2005) used the World Wide Web as an adaptive learning environment for teaching oxidation-reduction reactions for students in the experimental group and non-adaptive learning for students in the control group. The students from the adaptive and non-adaptive groups were students who offered ‘Life Chemistry’ as one of their courses. The findings of Own (2005) showed that students from the adaptive learning group performed far better in the concept of oxidation-reduction reactions to students from the non-adaptive group. Udo (2011) found out that problem-solving approach assisted students to perform better in oxidation-reduction reactions when compared to guided-discovery and expository approaches of teaching.

From Barke (2012), when a small envelope of a sheet of copper was heated with a flame, the exterior part of the copper was darkened whereas the interior part was left as coloured copper unaffected by the flame. Barke (2012) observed that 59.0% of students indicated that the exterior part was made of black soot, 18.0% of the students indicated that the copper had been combusted and 4.0% of the students indicated that the atoms of copper had changed. However, this situation was that of oxidation-reduction reaction and only 21.0% of the students indicated correctly that oxidation-reduction reaction had occurred. Barke (2012) then explained that this was due to the students' lack of practical experience of the concept of oxidation-reduction reaction.

From Ingvarsson (n.d.), an approach to teaching could be considered as useful when the approach considers a complex process in a concrete way and serve as a conceptual framework for students; when the approach assists students to find a proper progression in their learning process; and when the approach considers students relevant previous knowledge in chemical concepts to the new chemical concepts. Hammond, Austin, Orcutt, and Rosso (2001) identified that all modern teaching approaches identify themselves the role of experience and reflection in the development of ideas and skills. Such approaches appreciate the impact of culture and other influences on experiences relating to how students construct meaning and develop abilities. One of such teaching and learning approaches recommended by the planners of the Ghanaian Chemistry Syllabus for the high schools is participatory learning (MOE, 2010). Characteristically, participatory learning is practical and collaborative, reflexive in process, and purposefully in bridging the gap between theory and practice in a classroom (Trauth-Nare & Buck, 2011). Maija (1991) viewed participatory learning as the one that offers students the opportunity to 'learn how to learn' and to take control of their own learning from the start. From Landcare Research (2002), if the instruction is participatory oriented, and then students must be more active during instruction. This is because an active involvement of students in participatory instruction bestows on them a sense of ownership of the instruction, which develops in them an interest in learning and reduces the anxieties and uncertainties of learning (Maija, 1991).

Studies have shown that there were difficulties associated with the teaching and learning of the concept of oxidation-reduction reactions (De Jong, Acampo, & Verdonk, 1995; De Jong & Treagust, 2002; Udo, 2011). From De Jong et al. (1995), teachers consider the teaching and learning of oxidation-reduction reactions as one of the most difficult chemical concepts. The areas of difficulty from the perspective of the teachers was the explanation of the electron transfer model of oxidation-reduction reactions to students (De Jong et al., 1995) and the consideration of oxidation and reduction reactions as two separate reactions (De Jong & Treagust, 2002). From the review of literature, Udo (2011) asserted that notwithstanding the numerous importance of oxidation-reduction reactions in nature, technological development, and everyday life, the teaching and learning of oxidation-reduction reactions in schools and colleges is said to be a difficult one. There was therefore the need to investigate students' conceptions on oxidation-reduction reactions as well as the nature of the difficulty that could impede students' conception of oxidation-reduction reactions. Consequently, the investigation could lead to the way forward for teaching and learning of oxidation-reduction reactions which could improve students' conception.

Statement of the Problem

According to Harrison and Treagust (1998), students are faced with the difficulty of and even at times confused with the conception of the four models of the concept of oxidation-reduction reactions. Barke (2012) has suggested that only one model of oxidation-reduction reactions should be taught at one particular time or the other and the oxygen model of learning oxidation-reduction reaction should be avoided. This is because the oxygen transfer model has an appeal to students such that students most of the time conceptualise the oxidation-reduction reactions in terms of the oxygen transfer model. However, it could be said that not all oxidation-reduction reactions involve the transfer of oxygen.

In Ghana, the WASSCE Chief Examiners' Report on chemistry has continuously identified the concept of oxidation-reduction reactions as one of the difficult areas for most students (WAEC, 2004; 2005; 2006; 2007; 2008; 2009; 2011; 2012; 2013). For instance, in 2004, the Chief Examiner's Report explained that the candidates' performance in a question on oxidation-reduction reactions was poor. This was because the candidates could not identify the strongest oxidising and reducing agents in these three chemical equations:

$Mg_{(s)} + Zn^{2+}{}_{(aq)} \rightarrow Mg^{2+}{}_{(aq)} + Zn_{(s)}$,

$Zn_{(s)} + Cu^{2+}{}_{(aq)} \rightarrow Zn^{2+}{}_{(aq)} + Cu_{(s)}$,

$Cu_{(s)} + Ag^{2+}{}_{(aq)} \rightarrow Cu^{2+}{}_{(aq)} + Ag_{(s)}$ (WAEC, 2004, p. 213).

In 2005, the Chief Examiner's Report showed that some candidates could not determine the number of moles of electrons transferred in a given chemical equation. This happened because the candidates could not balance the chemical equation. In 2006, the report revealed that the candidates could not arrange elements in the order of reactivity with respect to the electrochemical series and that the candidates also had no practical experience in the area of oxidation-reduction reactions. In 2008, the Chief Examiner's Report state thus:

In question 4 most of the candidates could not distinguish between oxidation and oxidising agents as well as reduction and reducing agent. Candidates were asked to define the terms oxidising agent and reducing agent in terms of electron transfer. However, most of them defined oxidising agent as a substance which adds oxygen. Rather oxidising agent is a substance which accepts electrons or electron accepter and reducing agent is a substance which donates electrons/electron donor (WAEC, 2008, p. 38).

These reports suggest that students have difficulties in responding to examination questions on oxidation-reduction reactions at the SHS level. There was therefore the need to investigate the teaching and learning of oxidation-reduction reactions to appreciate the difficulty and also identify the most appropriate way for teaching and learning the concept at the SHS level.

Purpose of the Study

The purpose of the study therefore was to design and develop an alternative way of teaching oxidation-reduction reactions to enhance chemistry students' conceptual understanding of oxidation-reduction reactions. In doing so, there was exploration of how oxidation-reduction reaction was taught among SHS in Ghana and, valid and practical interventions were designed with the aim of improving students' conceptual understanding of the concept of oxidation-reduction reactions at the SHS level.

Research Questions

The study therefore sought to answer the following research questions:

1. What are the types of students' alternative conceptions and other difficulties related to oxidation-reduction reactions?
2. What makes teachers ineffective in teaching oxidation-reduction reactions?
3. Drawing on the research literature what techniques and strategies can be used to promote students' conceptual understanding of oxidation-reduction reactions?
4. What is the effectiveness of the new teaching approach in terms of chemistry students' conceptual understanding of oxidation-reduction reactions?
5. What are the views of students on the new teaching approach for students' conceptual development of oxidation-reduction reactions?

Significance of the Study

The findings from this study such as the alternative conceptions and difficulties chemistry students encounter on oxidation-reduction reactions would help teachers of chemistry in general and those who teach oxidation-reduction reactions specifically to appreciate the nature of the difficulties students encounter in learning oxidation-reduction reactions, and therefore create the enabling environment necessary to overcome such conceptual difficulties.

The study would further provide teachers, curriculum developers, and researchers in the area of chemistry education with rich quantitative and qualitative information about the appropriate instructional materials for teaching the concept of oxidation-reduction reactions. This would help chemistry teachers to employ the appropriate intervention for helping SHS chemistry students to improve their conceptual understanding of another important aspect of chemistry.

The findings from the study would also challenge researchers in chemistry education to conduct further studies in the area of oxidation-reduction reactions to assure the scientific community the way forward in teaching oxidation-reduction reactions. Thus the methodological guidelines for the design, development, and evaluation of interventions could further be stretched by other researchers in other parts of the world working under similar or different conditions in comparison to that of Ghana.

Delimitation

The concept of oxidation-reduction reactions is studied at the high school, college, and university levels; however, the study was delimited to the high school level. At the high school level, the study was confined to chemistry students in schools in the Ashanti Region of Ghana. The purpose of delimiting the study to students at the SHS was that the Ghanaian students are first introduced to oxidation-reduction reactions as a concept at the SHS level. It was therefore envisaged that an appreciable students' understanding on the concept at the SHS level could serve as a springboard for enhance performance at higher levels of chemistry education.

From MOE (2010; 2012), there were various chemical concepts for teaching and learning at the SHS level, however the study was delimited to the teaching and learning of oxidation-reduction reactions. Under the oxidation-reduction reactions there were six units and the study was delimited to the first two units. The two units were oxidation-reduction processes and oxidising-reducing agents; and balancing of redox reactions. It was hope that when students are able to conceptualise these concepts they can do well in the other four.

Limitation

The adoption of pretest-posttest single group quasi-experimental design for the real classroom teaching using the intervention meant that the students involved in the teaching try-out of the prototype stage were sampled from one school. The findings from the study on improving students' conceptual understanding of oxidation-reduction reactions was therefore not generalised to cover all Ghanaian SHS chemistry students.

Organisation of the Study

There are five chapters in the thesis; Chapter One and four other chapters which are organised to give further meaning to issues raised in Chapter One. Chapter Two reports on the review of related literature. The areas considered include alternative conceptions, concept of oxidation-reduction reactions, and difficulties associated with teaching and learning of redox reactions. The rest are participatory learning, learning theories, teaching and learning strategies, and designed-based research.

Chapter Three reports on the methodology of the study. That is the methods use in data collection and processing. The methodology is structured based on the concept of design-based research approach. The design-based research approach is composed of preliminary stage, design and development stage, prototype stage, and systematic reflection and documentation stage.

Chapter Four reports on the presentation and discussion of the results obtain from the various data collection instruments. The results and discussion are presented in line with the five research questions.

Chapter Five is the final chapter of the thesis and as such the concluding chapter. It reports on the summary, conclusions, and recommendations. It also reports on suggested areas for further research work. The key findings, conclusions, and recommendations are presented with respect to the stages of the design-based research approach and their research questions.

CHAPTER TWO

LITERATURE REVIEW

The chapter looks at both theoretical and empirical research works relating to teaching and learning of chemical concepts. The areas of review include alternative conceptions, concept of oxidation-reduction reactions, and difficulties in teaching and learning of redox reactions. The rest are participatory learning, constructivism, pedagogical content knowledge, teaching and learning strategies, and design-based research. The review is done to justify how well the study is grounded in literature and the basis for some decisions taken in the course of the study.

Alternative Conceptions

From the literature, conception has been described in diverse forms by different authors. Conception is the way people make theory and hypothesis and think about how they perceive every aspect of the world (Pratt, 1992). Students' conceptions are simply mental models of learning from one academic year to another (Richardson, 2011). Conception is simply a general learning experience (Boulton-Lewis, 2004; Entwistle & Peterson, 2004) and from Chan (2007), conceptions of learning are the beliefs and understanding students have about learning.

Chan (2007) wrote that students' conceptions of learning can be grouped as quantitative and qualitative conceptions. From Biggs and Moore (as cited in Chan, 2007), the quantitative conception is the quantity of knowledge students acquire and reproduce and qualitative conception is the students' abstraction of meaning and personal change through the process of learning. Saljo's five different conceptions of learning are increase of knowledge; memorising; the acquisition of facts, and procedures, which could be retained and/or utilised in practice; abstraction of meaning; and interpretative process aiming at the understanding of reality (Boulton-Lewis, 2004; Burnett, Pillay, & Dart, 2003; Kapucu & Bahcivan, 2014; Richardson, 2011). Saljo's first three groups of conceptions of learning are reproductive conceptions of learning and the next two are reconstructive conceptions of learning (Richardson, 2011).

Burnett et al. (2003) explained that the quantitative and qualitative groups of conceptions of learning are contrasting with deep and surface learning which are built upon meaning making and memorisation. From Boulton-Lewis (2004), Saljo's first three lower categories are all quantitative learning and surface in nature and the next two or three as justified by other studies are all qualitative learning and deep in nature. The lower conceptions are about memorising information and higher conceptions are about making meaning of information. In this thesis students' conception is the meanings they make of something.

According to Entwistle and Peterson (2004), Saljo explained that students' conceptions are influenced by specific context and from Burnett et al. (2003) students' conception of learning is affected by previous experiences they may have had with teachers and parents. Richardson (2011) found that how students perceive the context of learning influences their learning strategies and this is open to other interpretations and how students approach learning is influenced by their conception of learning. Richardson went further that students' conceptions of learning are relatively stable across a programme of learning.

Kapucu and Bahcivan (2014) reported that there is difference between male and female pre-service elementary science teachers' conception of learning science in the dimensions of memorising and testing, which are traditional conceptions of learning. The mean scores of the male pre-service teachers are higher than the mean scores of the female pre-service teachers. They appreciated that their finding is in agreement with that of Aypay but in disagreement with Chan et al. on the traditional conception of learning. Kapucu and Bahcivan (2014) further reported that there is no difference in pre-service teachers' conception of learning with respect to their socio-economic status such as family income and educational level of parents.

From Alamdardoo, Moradi, and Dehshiri (2013), there is a strong relationship between all pre-university students' conception of learning and their academic achievement. Additionally, there was a strong relationship between pre-university students' number of conceptions of learning and their academic achievement. From Burnett et al. (2003), there is a relationship amongst student self-concept, conceptions of learning, and strategies to learning; where student self-concept mediates between conceptions of learning and strategies to learning. Alamdardoo et al. (2013) inferred from their findings that students' conception of learning make them more flexibly in thinking and active in information process.

Students' conceptions are given more than one name; preconception, alternative conceptions, misconceptions, alternative frameworks, common-sense concepts, initial conceptions, pre-scientific conceptions, and everyday conceptions in the Science Education literature (Gaitano, Scharfenberg, & Bogner, 2013; Gonzalez-Espada, 2003; Guest, 2003; Mdachi, 2012; Osman & Sukor, 2013; Yip, 1998). In this thesis, alternative conceptions will be used as it is 'gentle' on students and do not look down on their conception of concepts.

Alternative conceptions are ideas students have about concepts which are contrary to those held by mainstream scientists (Guest, 2003; Wenning, 2008; Yip, 1998). Alternative conceptions are students' ideas different from those accepted and kept by students of all ages and of different origins (Guest, 2003; Hewson, 1992). It must be noted that some alternative conceptions may make sense but are not in line with acceptable scientific explanations (Guest, 2003).

Guest (2003) explained that alternative conceptions are used to describe a state in students' learning where they made no meaning of the scientific concepts. In this study "alternative conceptions are the conceptual difficulties students could have in explaining chemical concepts which end up not being in line with what is accepted in the scientific community" (Adu-Gyamfi, Ampiah, & Agyei, 2015, p. 745).

According to the National Research Council [NRC] (1997), alternative conceptions can be grouped into five categories. These categories are preconceived notions (which are popular students' conceptions based on everyday experiences); nonscientific beliefs (which are students' conceptions developed from sources such as religious and mythical teachings as oppose to science education); conceptual misunderstanding (which are students' conceptions developed from science lessons that fail to help students confront their own preconceived notions and nonscientific beliefs); vernacular misconceptions (which are students' conceptions of scientific words with other meanings in everyday life); and factual misconceptions (which are students' conceptions developed from false ideas learnt at the early ages and have remained unchallenged into the adult age).

Talanquer (2006) reported on four categories of heuristics reasoning underlying students' alternative conceptions. The four categories are:

1. Association: is where students blindly apply simple associative rules. For instance, the tendency of students to choose the cause of a phenomenon as the factor that is always present when the effect is experience; assume that there is a causal relationship between cause and effect; associate events that are close in time and space; think that effects in systems are linear and equally distributed; and select relevant causes in relation to their counts.
2. Substantialism: is where students simplify any analysis of a situation or concept by reducing factors present. For instance, the tendency of students to explain changes in a system with respect to a single variable; and use a single idea of various labels to explain a process.
3. Fixation: is where students' application of principles, strategies, and interpretations are done in automatic way without any respect for other things. For instance, the tendency of students to apply general principles and laws with no consideration for the true characteristics of the system where the process is taking place; solve any other problem encountered

with the same strategy that worked in a previous one; and assume that models and symbols are unique with well-defined interpretations that can be considered at face value.

4. Linear sequencing: is the tendency of students to structure and analyse any evolution of a system as line of chains of events. Thus, there is consideration for each variable at a time (Talanquer, 2006).

Talanquer (2006) gave a caution that the complexity of students' conceptions in chemistry cannot be reduced to a limited number of assumptions and simple reasoning applied in the same way with no consideration for the context.

Yip (1998, p. 102) classified alternative conceptions into three categories as: "informal ideas formed from everyday experiences; erroneous ideas developed during teaching due to lack of understanding; and wrong concepts propagated by teachers and books". It could be deduced from Yip that there are a number of sources of alternative conceptions. These include daily life experiences, folklore, curriculum and textbooks, media, language, and school instructions (Chiu, 2005; Gooding & Metz, 2011; Guest, 2003). Students themselves could be the source of their own alternative conceptions (Gooding & Metz, 2011) as alternative conceptions are caused by inadequate mental structures with which students learn concepts which are related and these mental structures through stepwise development (Chiu, 2005). From Wenning (2008), alternative conceptions results from students' attempt to give meaning to new experiences in the light of existing experiences.

According to Guest (2003), Harlen reported that students' alternative conceptions are built on what they perceived with their senses. That is to say that commonsense reasoning is the source of many alternative conceptions (Talanquer, 2006). For example, wet wood cannot be burnt because it contains water, reduction process results in conversion of compounds to the elements (Chiu, 2005), condensed water on the outside of a glass is the particles of water that had filtered through the glass wall (Talanquer, 2006), and in balancing redox reaction in basic medium, OH^- ions are added as the system is characteristically basic (Adu-Gyamfi et al., 2015).

Other examples of alternative conceptions in oxidation-reduction reactions include: in electrochemistry, "electrons travel through solution from one electrode to the other" (Osman & Sukor, 2013, p. 437); and in balancing oxidation-reduction reactions, H_2O is added to dilute the acid in the system, H_2O is added to combine with base, H^+ is added because the reaction is in acid, and OH^- is added to accept proton in basic medium (Adu-Gyamfi et al., 2015).

From the work of Talanquer, (2006), heuristics, which are students' attempt to make meaning of concepts and physical phenomenon using relatively simple to apply processes, are sources of alternative conceptions. Thus, common-sense reasoning is built on the use of heuristics. Wenning (2008) explained that alternative conceptions originate from misunderstanding, miscommunication, miseducation, and misapplication of scientific concepts and ideas. Salame, Sarowar, Begum, and Krauss (2011) pointed out that students' alternative conceptions develop from confusion amongst concepts. In the case of Salame et al., there was confusion between atomic mass and atomic radius.

Students' alternative conceptions could result from lack of critical observation and right follow-up discussion; and improper instruction by parents, teachers, or peers. Teachers should therefore appreciate that alternative conceptions are not naive viewpoints (Wenning, 2008) but a combined concept of common-sense experiences and partly correct scientific information (Gonzalez-Espada, 2003). Students fail to develop correct understanding of basic concepts at the start of their learning and the shortfall can easily disturb any subsequent learning (NRC, 1997).

Alternative conceptions are students' explanations that are not consistent with scientifically accepted ones and they are built on regurgitation, mnemonic use, coincidence, or guessing (Salame et al., 2011). Teachers who fail to identify any consistency in students' thinking consider alternative conceptions as un-harmonised pieces of information (Talanquer, 2006).

Though NRC (1997) reported that students can easily overcome vernacular and factual misconceptions but not preconceived notions and nonscientific beliefs; current research has shown that it is difficult to change alternative conceptions (Salame et al., 2011). According to Wenning (2008, p. 12), "students' alternative conceptions are very difficult to change; only very specific learning approaches have shown promise of getting students to accept new explanations". This is because they are intuitive and fruitful to students (Guest, 2003) and if an alternative conception remains for too long a time in the alternative conceptions should adopt activities that will weaken the existing conceptions to give way to improve conceptual understanding of new concepts (Wenning, 2008) and this is not as simple as may be perceived (Gonzalez-Espada, 2003).

Gooding and Metz (2011) asserted that there are many common alternative conceptions and the first step to dealing with them is to identify those alternative conceptions. However, to categorise individual student's alternative conceptions as superficial or deep, there is the need for teachers to listen to and analyse student's responses. Thereafter, teachers should seek clarification and demand explanations and discussions from the individual student.

Alternative conceptions are sources from which teachers can instruct students to enhance their conceptual understanding on chemical concepts (Talanquer, 2006). To address alternative conceptions and enhance students' conceptual understanding on chemical conceptions, Osman and Sukor (2013) recommended that teachers should adapt to the use of constructivist instruction and cognitive scaffolding. For example, structured discussion provides students opportunities to deal with their alternative conceptions.

Teachers need to identify alternative conceptions if not it will be difficult to address them (Salame et al., 2011) and the best way of identifying alternative conceptions is by the use of diagnostic test (Osman & Sukor, 2013). The reason being that, any teacher instruction that fails to identify and analyse alternative conceptions will not enhance students' conceptual understanding. Teachers' pedagogical content knowledge develops as they encounter students' alternative conceptions in the teaching process. That is teachers tend to examine the content and the strategies used in teaching it (Mdachi, 2012).

NRC (1997, p. 31) report suggested the following as ways of helping students overcome their alternative conceptions:

1. Anticipate the most common alternative conceptions in relation to a concept and be ready for any other.
2. Encourage students to test their conceptual frameworks by creating opportunities for students to discuss among themselves.
3. Think of ways of addressing common alternative conceptions with demonstrations and laboratory work.
4. Take a second look at alternative conceptions frequently.
5. Assess and reassess the validity of student concepts.

Concept of Oxidation-Reduction Reactions

From history, the four models of oxidation-reduction reactions are oxygen model, hydrogen model, electron model, and oxidation number model. The four models are said to be important to chemistry education today (Osterlund, 2010). According Osterlund (2010), Stahl identified that all materials that can be combusted contain phlogiston and that materials such as ash do not contain phlogiston and therefore cannot burn. In the extraction of metals from their ores, phlogiston-free oxide ores are burnt in phlogiston-rich charcoal and as a result the phlogiston component from the charcoal moves to the oxide ores. The charcoal then becomes phlogiston-free and the oxide ore becomes phlogiston-rich metal. Lavoisier further found that there is a gas component of air which is phlogiston-free air (oxygen) that made glowing stick flare up. This combustion, which is addition of oxygen to combustible material is referred to as oxidation (Osterlund, 2010). For example,

$CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(l)}$

Osterlund (2010) reported that Liebig considered oxidation as loss of hydrogen. Liebig explained that an organic molecule could be reduced by the addition of hydrogen or could be oxidised by the removal of hydrogen. For example, primary alcohols lose two atoms of hydrogen to form aldehydes. In the mammalian system, ethanol is oxidised by alcohol dehydrogenase to form acetaldehyde (Fessenden & Fessenden, 1990):

$CH_3CH_2OH \rightarrow CH_3CHO + 2H$

According Osterlund (2010), after the concept of oxidation as addition of oxygen and loss of hydrogen, Arrhenius used Faraday's concept of ions in solution to study oxidation. Arrhenius explained oxidation as an increase in an ion charge and reduction as a decrease in ion charge of specie. For example,

$Fe \rightarrow Fe^{2+} \rightarrow Fe^{3+}$

$Fe^{3+} \rightarrow Fe^{2+} \rightarrow Fe$

Osterlund (2010) explained that the fourth and the last description of oxidation came as a result of Lewis concept of shared pair of electrons in a covalent bond. In covalent bonds such as HCl, electrons are incompletely transferred from one of the bonded atoms to another and the oxidation numbers of the atoms can be determined. When the oxidation numbers are determined, oxidation could be described as increased in oxidation number and reduction is decreased in oxidation number. "A reaction that does not show a change in oxidation number of any of its elements is not a redox reaction" (Ameyibor & Wiredu, 1993, p. 424). This is because oxidation-reduction reactions occur as a result of competition for electrons by the atoms of elements involved in the formation of new substance.

Osterlund (2010) observed that the concept of oxidation-reduction reactions can be applied in both inorganic and organic chemistry. Kunitomo, Fujiwara, Takamoto, and Onuma (2006) explained that in a blast furnace the process of producing pre-reduced iron ore is achieved by the presence of natural gas consisting of hydrogen and carbon monoxide. The natural gas is the substitute for the coal in order to decrease carbon dioxide emission.

There are two approaches to balancing oxidation-reduction reactions. These are oxidation number method and half reaction method (Romero, 2009). The half reaction method is also referred to as the ion-electron method for reactions occurring in both acidic and basic media (Chang, 2003). In the procedure for balancing oxidation-reduction reactions, the H_2O, H^+, and OH^- species are introduced at the fourth stage. Any oxygen (O) atoms are balanced with the oxygen atoms from H_2O species and any hydrogen (H) atoms are balanced with H^+ species in acidic medium. In the basic medium however, H^+ ions are neutralised with OH^- species on both sides of the equations to form H_2O molecules (Chang, 2003; Romero, 2009).

Difficulties Associated with Teaching and Learning of Redox Reactions

Chemical concepts like any other scientific concepts are associated with conceptual difficulties and a number of research works have identified some of such difficulties in the area of teaching and learning of chemistry (Adu-Gyamfi, Ampiah, & Appiah, 2012; Ali, 2012; Bond-Robinson, 2005; De Jong, Acampo, & Verdonk, 1995; De Jong & Treagust, 2002; Felder, 1993; Hanson, 2010; Zoller, 1990). Students who are sensors see chemical concepts as difficulty. This because such concepts are presented using theories and formulae (Felder, 1993).

From Zoller (1990), the switch between macroscopic and microscopic learning of chemical concepts is a source of difficulty among students learning chemistry. In the area of oxidation-reduction reactions, this macroscopic and microscopic interplay is experienced in balancing of oxidation-reduction reactions. According to Osterlund and Ekborg (2009), students' failure to appreciate that oxidation and reduction reactions occur simultaneously but not mutually exclusive reactions meant that the difficulty of students with respect to oxidation and reduction reactions still exist out there.

Bond-Robinson (2005) wrote that students' difficulty in learning chemical concepts stem from the fact explanations in chemistry requires students to use the multiple means with which chemists reason in relation to chemical process. Hanson (2010) identified that the difficulty of students in chemical concepts is partly due to students' inability to correctly write and balance chemical equations.

Ali (2012) explained that the difficulty in teaching and learning of chemical concepts is as a result of the way topics are sequence in chemistry curriculum materials such as textbooks. That is some chemical concepts are not spiralling enough where understanding in one concept leads to better understanding of the next topic. For instance, Ali found that the chemistry teachers who participated in his study preferred the teaching of Periodic Table ahead of any other chemical concepts like valency as it is a key to better understanding of such concepts, and hence should be the first chapter of the textbook the teachers were using (Ali, 2012).

Students' perception that oxygen always forms part of oxidation-reduction reactions contribute to their difficulty in learning oxidation-reduction reactions (Osterlund & Ekborg, 2009). It was observed by De Jong et al. (1995) that chemistry teachers have a difficulty in helping students to accept the electron model as the concept for explaining and identifying oxidation-reduction reactions. In addition Osterlund and Ekborg (2009) observed that notwithstanding the number of months the electronic model of explaining and identifying oxidation-reduction reactions was taught in their study, very few students involved in the study were able to adopt the concept in explaining the situations of oxidation-reduction reactions given. This is an indication that we need to look at the chemical concept of oxidation-reduction reactions in the context of the model that should be used in teaching.

Osterlund and Ekborg (2009) found out that students have no difficulty in identifying reducing agents but have difficulty in identifying the oxidising agent. This is partly because the students conception of oxidation is basically associated with oxygen and hence, for reactions involving molecular oxygen, it easier for the students to identify it as the oxidising agent. Students even see an atom of oxygen in a molecule or compound such as water (H_2O) as being responsible for oxidation; thereby referring to the molecule as the oxidising agent (Osterlund & Ekborg, 2009).

Participatory Learning

From Pain, Whitman, and Milledge (2011, p. 2), participatory approach "is a set of principles and practices for originating, designing, conducting, analysing, and acting on a piece of research." The study of Liu, Tseng, and Wu (2013) revealed that a number of learning strategies evolved in teaching a concept through participatory approach. They identified strategies such as completion, confirmation, repetition, recall, inquiry, and extension. Two descriptions of participatory approach could imply that the approach has no particular methods that should be adopted for a research work or instruction but methods are selected as and when the need arises (Pain et al., 2011).

In research works involving participatory approach, the participants are involved in planning, action, and reflection of the day's activities, and evaluation (Pain et al., 2011). Greenwood, Whyte, and Harkavy (1993) found that where there was participatory in research, the collaboration between the researcher and the classroom teacher encouraged the integration of local content into instruction. Su, Chiu, and Wang (2010) noted that participatory approach is that of repetitive and based upon formative evaluation process. Landcare Research (2002) reported that participatory learning makes use of groups and teams during instruction. The team for instructing a concept in an academic institution usually consists of teachers, designers, and researchers. All team members are involved in the entire process of instructional design (Su et al., 2010) and it creates a sense of ownership amongst the participants (Andriessen, 2006).

Trauth-Nare and Buck (2011) found that participatory research enables researchers and practitioners develop pedagogical knowledge and skills in the area of assessment. It further ensures a two-way communication system between the target and the researchers. This could be achieved by creating a forum where participants can share their views on the programme or instruction. Borko (2004) reiterated that researchers can use individual student activities to study their evolving knowledge or use students' group activities as unit of analysis to study patterns of students' participation in lessons.

Landcare Research (2002) observed that participatory learning makes use of task, which is the definition of the day's problem, and process, which is the way people team together solving the problem and the instruction is an evolving one which cannot be considered as a single event and takes time as a process. This is to say that participatory instruction is a complex process and no single approach could be sufficiently enough to execute it (Landcare Research, 2002). This complex process is accompanied with formative assessment where "formative assessment is not simply a cognitive process for eliciting understanding, but rather a fundamentally relational act in which teacher and students can participate, construct, and coordinate classroom processes" (Trauth-Nare & Buck, 2011, p. 396).

According to Trauth-Nare and Buck (2011), participatory approach is practical and collaborative, reflective in process, and purposefully in bridging the gap between theory and practice in a classroom. Reflection is an important feature of participatory approach (Pain et al., 2011; Trauth-Nare & Buck, 2011). The study of Trauth-Nare and Buck (2011) has shown that teachers involved were not used to reflecting on students' output. However, the teachers at the end of the study appreciated that reflection on students' formative assessment is important for making important instructional decisions that takes care of students' learning needs. According to Pain and his colleagues, after each engagement using participatory approach, there should be at least 15 minutes roundup (reflection) which has the potential of slowing down instruction or project but it is important to help get to the target (Pain et al., 2011). Trauth-Nare and Buck (2011) asserted that through participatory reflection, they (the research team) appreciated how to put into practice the theoretical viewpoint of formative assessment in real science teaching and learning setting.

Participatory learning is not like seeking an expert view but it is an evolving process that makes use of more than one instructional approach (Landcare Research, 2002). This makes participatory approach characteristically collaborative (Foster, Dimmock, & Bersani, 2008; Su et al., 2010; Trauth-Nare & Buck, 2011). From Su et al. (2010), participatory approach to learning considers knowledge by doing. It requires that designers of instruction which is participatory should involve the end users in designing rather than designing it for them to use. That is users are seen as partners and their knowledge is valued in the design process. Participatory approach considers the views of all participants. That is participatory approach is collaborative and not left at the door steps of only the developers to plan and develop the instruction (Foster et al., 2008).

Pain et al. (2011) explained participatory approach as collaborative involving people who in one way or the other are affected by a situation and interested in developing and using the new knowledge. Hence, Chuen, Majid, Rahman, Dahlan, and Atan (2008) proposed that learning in today's world must involved students in a learning environment that is collaborative which enhances meaningful construction of knowledge through the process of critical thinking as such as discussion.

According to Pain et al. (2011), in participatory approach the role of a facilitator is one of importance; and to make participatory approach collaborative enough, the role of a facilitator should be rotated. However, the facilitator's role should be moderated in such way that the facilitator will not dominate group meetings when he/she is of some expertise in the area being discussed. That is in participatory approach everybody within the group should be given the opportunity to make contributions (Pain et al., 2011) and there is the need for a continuous follow-up to ensure that the participants are well informed for effective participatory approach.

Participatory approach is collaborative in learning as students create and solve problems as well as evaluate and settle disputes with respect to colleagues' solutions (Shen, Wu, Achhpiliya, Bieber, & Hiltz, 2004). Disputes are important aspect of participatory teaching and learning processes as students are given the opportunity to read their colleagues solutions to problems and therefore could argue on the correctness of some solutions. Shen et al. (2004) therefore emphasized that teachers should carefully review students' solutions presented to the class ahead of scoring to avoid disputes. UNESCO (2001) explained that group discussion is a useful participatory instruction tool as through group discussion students learn to agree, disagree, and have mutual respect for the views of other students.

The number of approaches that is used in participatory approach always results in an increased level of satisfaction. Shen et al. (2004) concluded their work saying that the student-centered nature of participatory approach enables students to appreciate and develop interest in topical issues in class. According to Maija (1991), the International Teaching Center at the Baha'i World Center identified participatory approach as one of the elements that made great impact on the success of the special educational activities.

According to McLoughlin and Lee (2007, p. 664), in participatory learning "learners are active participants or co-producers rather than passive consumers of content, and so learning is a participatory, social process supporting personal life goals and needs." From Shen et al. (2004, p. 1), participatory learning approach engages "students as active participants in the full life cycle of homework, projects, and examination." From the two definitions, it could be seen that students are basically active learners in participatory learning environment. This is partly because students have the opportunity to negotiate for the objectives, knowledge, skills, attitudes, or the teaching and learning methods of a

Liu et al. (2013) further found that in participatory learning, collaboration assisted e-book readers variety of forms of interaction and Chuen et al. (2008) added that success is collaborative which is achieved through the contribution of each student from the groups in a collaborative lesson. UNESCO (2001) emphasized that students achieve more and become more satisfied when they are actively involved in the teaching and learning process; and that students' active participation in lessons is an effective part of their learning of concepts (Liu et al., 2013; McLoughlin & Lee, 2007). The opportunities given to students such as disputing solutions and reading or observing colleagues' solutions in a participatory lesson provide them with opportunities to view subjects or course from more than one perspective of importance (Shen et al., 2004).

In participatory learning, several forms of interactions evolve and inquiry-based learning can be fused into it to better assist students in designing, solving, and evaluating problems (Shen et al., 2004). The study of Liu et al. (2013) revealed that in a child-parent participatory lesson outside the regular classroom situation, the parents interacted with the children through demonstration, coaching, and independent interaction forms.

Theories of Knowledge Construction

There are a number of theories of learning that are of interest to the processes of knowledge construction. For the purposes of the current study, individual constructivist learning, social constructivist learning, and pedagogical content knowledge are discussed.

Constructivism

The concept of constructivism is used in diverse forms in the literature but its use in the current study is limited to constructivism as a learning theory. According to Osborne (1993), constructivist learning theories developed as a result of the necessary reaction needed at the time to counter the developmental stage model of cognitive growth. This is because the process of education should not only be transmission of knowledge. However, the process of education must position students in such a way that they can acquire and make meaning of constructs and modern scientific knowledge. Landcare Research (2002) explained that in a constructivist's paradigm, knowledge is constructed by each individual but not transmitted from one person to another.

Hein (1991) explained constructivism as a learning theory where students construct knowledge for themselves individually and socially as students make meaning of new materials. From Tetzlaff (2009), constructivist learning is student-centered learning theory where students make meaning of information as they handle concepts and reflect on their processes. Thus, students do not necessarily receive information from teachers but incorporate their experiences and views to make meaning of concepts. Lowenthal and Muth (2008) explained that constructivism is a learning theory built on the assumption that knowledge is constructed from an external reality. Hein (1991) found that constructivism is about the students making meaning of new material but not the subject, course, or lesson to be taught. According to Tetzlaff (2009), constructivism is characterised by active engagement, constructive, intentional, complex, contextual, collaborative, conversational, and reflective. Constructivism believed that students' learning is an active process where students make meaning of sensory inputs (Hein, 1991) and knowledge is something that students built on through partial, incorrect, or apparently unnecessary existing knowledge unless carefully guided (Taber, 2011).

Osborne (1993) noted that in the eyes of constructivists; students are important subject to consider and should be actively engaged in the process of meaning making (Jones & Brader-Araje, 2002). This is because students are responsible for their own learning. Constructivist learning theories make two claims about student learning. One is the fact that students' learning is impeded and channelled by the nature of students' built-in biases of cognitive apparatus, and the other is the fact that students' learning is dependent upon the individual student's cognitive resources used to interpret new experiences (Taber, 2011).

From Landcare Research (2002, p. 17), "teaching is the process that support this construction and reconstruction of new knowledge, rather than being the communication of knowledge." This means that authors of the research report (Landcare Research, 2002) agreed that classroom instructions should be channelled through the tenants of constructivism. There are three things that make constructivist learning theories very attractive. These are the role of the individual student, the importance of meaning making, and the active role of students in the teaching and learning process (Jones & Brader-Araje, 2002). A learning theory is described as constructivism with respect to some unique attributes. The attributes of constructivism identified by Wilson (2010) are:

1. the process of meaning making is an active one achieved through experience and interactions with the world;
2. through cognitive conflict, challenge or puzzlement students make meaning of activities;
3. meaning making involves collaboration, negotiation, and participation of students in authentic practices of communities;
4. students' reflection, assessment, and feedback in the natural setting enable students to make meaning of new information; and
5. students are responsible for meaning making.

Sjoberg (2007) reported that constructivist learning theories are characterised by the fact that

1. students actively construct meaning and meaning is not imposed on them;
2. students come to learning environment (lessons) with previous knowledge and experiences;
3. individual students have their own ideas about the world and these ideas are socially and culturally accepted and shared;
4. the individual students' ideas are most at times contradictory to accepted scientific ideas, concepts, and principles;
5. knowledge is part of the human brain as conceptual structures, which can be model and described in some detail;
6. teachers' instructional strategies need to take advantage of students' previous knowledge and experiences in order to change or challenge these knowledge and experiences; and

7. students construct their individual knowledge collaboratively through social, cultural, and linguistic interactions with the physical.

Jones and Brader-Araje (2002) asserted that the introduction of constructivism has helped change the focus of knowledge as a product to knowledge to, as a process of knowing and according to Brown (2005), constructivism is currently the most important learning theory for educational policies, models, and practices. Osborne (1993) emphasized that the purpose of constructivism was due to the fact that all over the world teaching and learning process was dominated by didactic strategies and that constructivist strategies serve as a measure to address the shortfall in and to create a balance for students' learning. Tetzlaff (2009) explained that constructivist instruction can be combined with other instructions such as explicit learning to reduce the shortfall in teaching with the respective learning theories to enhance the social learning opportunities in the educational environment. Jones and Brader-Araje (2002) emphasized that constructivist learning theories offer teachers the opportunity to use instructional strategies that transcend beyond rote learning to meaningful learning.

In addition, Osborne (1993, p. 19) reiterated that "… an improved science education will only come through the critical review of arguments and research evidence and by the adoption of a pedagogy which places a value on variety and diversity and not on a singular ideology." Consequently, students come out of constructivist lesson feeling accomplish and confident as well as being able to use the acquired knowledge in new situations (Cooperstein & Kocevar-Weidinger, 2004).

From Brown (2005), constructivism is a learning theory where students make meaning of new information and social constructivism is a learning theory where students make meaning of new information as a result of their active participation in a community. With respect to social constructivism, meaning making is co-constructed by students. Richardson (2003) explained psychological constructivism as a learning theory where individual students actively make meaning of concepts, which is dependent upon the student's previous experience and knowledge. In psychological constructivist instruction, students make meaning within social group which provides students with the opportunities to share ideas. From the literature, Brown (2005) found that social constructivism is currently being placed ahead of all constructivist instruction. That is the teacher or no other person is the expert but the community of practice. From the works of Brown (2005) and Richardson (2003), more than one form of constructivism can be identified. Jones and Brader-Araje (2002); Sjoberg (2007) identified individual (cognitive), social, radical, and educational forms of constructivist learning theories. Richardson (2003) also identified two forms of constructivist learning theories as psychological constructivism and social constructivism. Lowenthal and Muth (2008) further identified two forms of constructivist learning theories as individual constructivism and social constructivism. This could be described as continuum with individual meaning making at one end and meaning making amongst group of individuals at the other end.

Ernest (2010) asserted that constructivist learning theory is not a single school of thought. There are several forms of constructivism and in some cases they oppose each other. For the purposes of the current study, two forms of constructivist learning theories are discussed as individual constructivism and social constructivism.

Individual (cognitive) constructivism: is accredited to Jean Piaget (Lowenthal & Muth, 2008; Sjoberg, 2007). According to Piaget's constructivism, students can make meaning of an abstract concept because humans are rich genetically with the potential to construct the apparatus necessary for abstract thinking through the process of iteration (Taber, 2011). From Lowenthal and Muth (2008), cognitive constructivist learning theory sees students' meaning making as relating to the individual student's previous knowledge and experience. That is Piaget's cognitive constructivism was centered on the development of the individual student. Cognitive constructivism has no interest in the socio-cultural context of students' meaning making of concepts (Jones & Brader-Araje, 2002) as knowledge acquired is constructed personally by individual student's active involvement in the learning process (Landcare Research, 2002; Taber, 2011).

Cognitive constructivist learning theory is based upon the fact that meaning making is built upon internal developed cognitive resources. Mental (cognitive) resources are referred to as schema in Piaget's scheme of knowledge construction (Swan, 2005). Students make meaning of concepts because whenever they encounter new concepts they use the previous cognitive resources to make sense of the new concepts. That is learning of concepts occurs whenever students develop cognitive resources for such concepts and build on them (Taber, 2011). Cognitive constructivist learning is simply an active mental process (Kruse, 2009; Landcare Research, 2002).

According to Torre, Daley, Sebastian, and Elnicki (2006), students learning under cognitive instruction use cognitive tools (such as insight, information processing, perceptions, and memory) to facilitate meaning making of new materials. Piaget explained that students' actively make meaning of concepts as a result of assimilation and accommodation of the new concept into their previous knowledge and experience (Jones & Brader-Araje, 2002), which are the cognitive resources. Assimilation occurs when students make meaning of new information through previous knowledge and experience and accommodation occurs when students need to change their previous knowledge and experience (that is their model) to a new knowledge (Chiva, Grandio, & Alegre, 2010). Consequently, students are usually found of revising and re-constructing their understanding of concepts in relation to the previous knowledge and experiences as time passes by (Jones & Brader-Araje, 2002).

There cannot be assimilation of new material where there are no existing cognitive structures to build on (Hein, 1991). That is from constructivist point of view, students need knowledge to make meaning of new material. From Taber (2011), Piaget's cognitive constructivism revealed that students make meaning of concepts by modification of existing models on the heels of feedback. It is worthy to note that cognitive strategies in the words of Osborne (1993) are not restricted to certain subjects but powerful set of general purpose procedures such as ability to analyse, reflect, and generalise. According to Torre et al. (2006), students learning under cognitive instruction use cognitive tools (such as insight, information processing, perceptions, and memory) to facilitate meaning making of new materials. Kruse (2009) wrote that students can make deep meaning of new concepts (whether assimilating or accommodating) by creating linkages between the existing conceptual framework and the new concepts.

Social constructivism: is accredited to Lev Vygotsky (Jones & Brader-Araje, 2002; Lowenthal & Muth, 2008; Sjoberg, 2007). Vygotsky emphasized the role of the communities, which include parents, teachers, peers, families, and acquaintances of students, in the process of meaning making (Hein, 1991). This is because the society has enormous influence on students' higher mental functions. This shifted the attention from the Piaget's cognitive constructivism and the behaviourist learning theory where the individual student was the focus to role of the larger community (Jones & Brader-Araje, 2002). According to Taber (2011), Vygotsky's considered the process of cognitive development as gradual one, which is personal, largely implicit, spontaneous concepts with the formal, but initially isolated and non-functioning academic concept.

From Ernest (2010); Landcare Research (2002), learning theories in the domains of cognitivists and constructivists are built upon the fact that students internally make meaning of new material based on the individual student's interpretation of the previous knowledge and experiences. Notwithstanding the individual student's internalisation of new information, the social constructivism explains that knowledge is co-constructed and that the community of students' learning is very important for meaning making. Social constructivism believed that there is collectiveness in some mental functioning such as group problem solving (Ernest, 2010). From Richardson (2003), social constructivism is built on the way power, economy, political, and social factors influence the way group of students make meaning of the world.

Vygotsky identified two origins of concepts; where students construct their own informal concepts and the other, where students learn 'scientific' or 'academic' concepts from others. The students' personal concepts are modified through social interactions (Taber, 2011). From Jones and Brader-Araje (2002), Vygotsky believed that student best make meaning of concepts in the light of the other peoples within his or her community.

According to Tetzlaff (2009), Wertsch explained that students internalise new observed behaviour when they are able to function the new into their internal system of behaviour regulation. Internalisation usually helps students to behave voluntarily without the assistance of teachers. Internalisation is the most effective result of social learning. This is because internalisation has long lasting impression on students' attitudes and behaviours (Tetzlaff, 2009).

The human mind is social and conversational. That is individual student's meaning making originate from internalised conversation. Social constructivism assigned importance to the social environment and interpersonal relations in teaching and learning process such as negotiation, collaboration, and discussion (Ernest, 2010). Social constructivists such as Vygotsky asserted that language is an important tool in the teaching and learning process (Ernest, 2010; Hein, 1991). This is because conversation in constructivism enables students to develop and expand their knowledge as a result of the exposure to new information and alternatives (Tetzlaff, 2009). From Lowenthal and Muth (2008), students make meaning of new materials through social interactions, within cultures, and through language and that language is the means of conceptual development and that students need language to facilitate higher order thinking (Jones & Brader-Araje, 2002).

Jones and Brader-Araje (2002) reported that Vygotsky believed that language, which is a psychological tool, causes a basic change in mental functions; helps to engage students in direct active meaning making aside language being used as a tool for communication; serves as that link between formal and informal concepts that students at the same time construct different meanings of the same phenomenon as a result of language usage.

Vygotsky's zone of proximal development is the point where students could not make meaning of concepts without a support but could make meaning with support from another who is more knowledgeable or experienced in the concept (Ernest, 2010; Kruse, 2009; Taber, 2011). The process of conventionalisation is at the heart of the zone of proximal development. That is conversation mutually help shape both individual and private meanings as well as collective and public expressions (Ernest, 2010). According to Jones and Brader-Araje (2002), Vygotsky explained the zone of proximal development as the intellectual potential of an individual student when assisted by another knowledgeable individual. Vygotsky believed that the zone of proximal development helps to measure the intellectual potentials of students. The assistance from the knowledgeable individual to students helps them in intellectual growth and self-regulation as students go through series of steps.

Constructivist learning theories further claim that different students presumed to be at the same starting point may differ in how they make meaning of new information beyond their existing knowledge and understanding. This brings to light that teachers should be in the known of the individual student's zone of proximal development and take advantage of it. Consequently, any teaching targeting the zone of proximal development can bring about further learning (Taber, 2011).

From Vygotsky's social learning theory, Taber (2011) found that students make meaning of concepts to a great extent through interactions with peers. This is because students who are approximately at the same level of development may help place their inputs within the zone of proximal development of each other student. Taber (2011) was emphatic about the fact that constructivist learning theories proposed that effective teacher instruction needs to be student-centered as well as teacher-directed. This is because at the zone of proximal development, teacher needs to monitor and direct learning.

Social interactions in constructivism are an opportunity for students to expand and modify their thinking and share ideas. Vygotsky espoused that social learning exposes student to knowledge that they may not be in the known (Tetzlaff, 2009). In social learning environment what students bring to bear on the new material consciously or unconsciously affect students' learning as they interact amongst members within the learning environment. The previous experiences could either reinforce meaning making or create cognitive discourse. Tetzlaff (2009) reiterated that the cognitive discourse can cause students to rethink about the previous knowledge thereby developing complex thinking as they attempt to create a balance between the previous knowledge and the new information.

From Tetzlaff (2009), Luria and Vygotsky were of the view that a long period of time is needed by students to make meaning of the new information they have been exposed to. This period of exposure can make students change their previous knowledge immediately, after sometime, or not at all. However, notwithstanding either of these changes, students' previous knowledge can be affected by their receptiveness to learning the new material. In social learning environment where students are aided by more experienced hands, there is maximum use of time and energy in constructing knowledge instead of the case where students are left alone to construct their own knowledge (Tetzlaff, 2009).

von Glasersfeld's idea of validity in knowledge construction was taking on board by social constructivists. Social constructivists believed that validity is not only limited to individual student's scheme of concept but the social context of the individual student as well. According to Jones and Brader-Araje (2002), the classrooms of teachers who value students' ideas and promote the process of critical thinking are the very conducive environment for testing ideas.

Under constructivism, teachers should have a good understanding of students' current knowledge level, what students need to learn, and the appropriate level and form of guidance to assist students make meaning of new material. When teachers are well vest in these areas of teaching and learning process, then they can design instructional strategies that can give high levels of the needed outcomes of learning (Taber, 2011) and can expose students to alternative thinking and behaviour as they observe and interact with each other (Tetzlaff, 2009). Thus, any teaching that targets beyond what is known and understood today facilitates meaningful learning (Taber, 2011). As such the social constructivist learning theory has informed the use of cooperative and collaborative instructional strategies such as peer-peer tutoring in today's classrooms (Jones & Brader-Araje, 2002). Social constructivism has further informed the classroom organisations such as small group work and whole class discussion in today's classrooms (Jones & Brader-Araje, 2002).

From Taber (2011), effective meaning making could only be possible when there is constant linkage between the current leaning and learning needs of students. This will help to scaffold the next learning activity. To achieve this, teachers should carefully monitor and regulate students' learning at the individual level. Monitoring of students' learning should be done by teachers with requisite levels of knowledge and skills. Students at school level will require considerable teacher assistance to direct their learning. An effective constructivist enquiry instruction will carefully guide students' learning within the zone of proximal development. That is teachers should provide careful scaffolds for students during constructivist enquiry instruction. Teachers using constructivist learning theories should be aware that students need time, space, and suitable experiences as scaffolds for learning. However, the needed learning outcomes could be achieved through minimal guidance by teachers (Taber, 2011).

One of the roles of teachers in social learning environment is to organise the new information. The organisation could include formation of metaphors and examples. Students easily built concepts upon each other in ascending complexity to make meaning of the new information when the information is effectively organised by teachers. Teachers must be consistent with the ways of presenting new information to students in social leaning environment to enhance their meaning making. Consistency is very necessary in order to avoid conflicting communication to students (Tetzlaff, 2009).

In a social learning environment, students respond to experience by the imitation of the behaviour of others. Vygotsky then said that individual students' ability to undertake certain activities is good grounds enough to start assuming that students have made meaning of the principles underpinning the new activities (Tetzlaff, 2009).

Lessons learnt from constructivist learning theories

From the constructivist learning theories discussed so far, social constructivist approaches focus on the development of formal knowledge whereas psychological constructivist approaches focus on the ways in which individual students make meaning in their minds and how shared meaning is developed as a result of group processes. In the process of formal knowledge constructivism, language is an important tool but issues of status, ideology, politics, and power are not important considerations under psychological constructivism as they are in social constructivism. However, both social and psychological constructivist learning theories assumed that students actively make meaning in their minds (Richardson, 2003).

Richardson (2003) acknowledged that the social factor of psychological constructivism is an important contribution, especially in the area of instructional strategies. This is to say that formal knowledge can be developed in a community of experts such as the classroom. Richardson (2003) was quick to add that "… the social aspect of psychological constructivism is not equivalent in focus, concept, or analytic level to social constructivism" (p. 1625). This is because the social aspect of psychological constructivism is just a process that helps to construct a shared knowledge of concepts. Social interaction through small group activities and discussions plays key role in students' meaning making as students learn and share knowledge. This is because social interactions offer students opportunities to verify their understanding and that social interaction is not necessarily limited to students' knowledge construction (Cooperstein & Kocevar-Weidinger, 2004).

The social and radical forms of constructivism were identified to have had enormous impact on teachers' instruction and curriculum design. This is because the two could easily be integrated into today's educational strategies (Jones & Brader-Araje, 2002).

Kruse (2009) appreciated that biological maturation and experience are factors that affect students' level of meaning making. Consequently, until students are developmentally ready to operate at the level of hypothesizing, teaching any concept at this level will result in rote learning to any meaning making for such concepts.

Notwithstanding the number of learning theories in the domain of constructivism, they all consider the student as an active participant of the teaching and learning process (Landcare Research, 2002; Ross & Nisbett, 1991). Students' meaning making is built upon mental structures from experience relating to the new information. The previously built mental structures serves as the content for follow up meaning making. Consequently to all forms of constructivism students' previous knowledge and experiences are very necessary for further meaning making (Ernest, 2010).

All constructivist learning theories asserted that knowledge is not external to the student (Jones & Brader-Araje, 2002) and teachers must therefore identify students' misconceptions and learning errors and deploy diagnostic teaching and cognitive conflict strategies to help students overcome these misconceptions and errors (Ernest, 2010). An effective instruction is dependent upon teachers' decision making with respect to teachers' knowledge of the content, subject pedagogy, and the nature of students in the class. Constructivist instruction is to provide students with optimum levels of instruction but not 'direct' or 'minimal' instruction (Taber, 2011).

From Richardson (2003) point of view, all constructivist instructional strategies use group work to facilitate shared knowledge of a concept; provide opportunities for students to determine, challenge, change, or add to previous experience and knowledge through engagement of students in structured; develop students' metawareness of their own understanding and learning processes; place the student at the centre of the teaching and learning process and take advantage of student's previous experience and knowledge. These identified elements of the instructional strategies that are constructivist oriented enable teachers to create constructivist learning environments, activities, and methods in their classrooms (Richardson, 2003).

Learning environment that provides students with the opportunities to explore, invent, and create gives teachers the chance to integrate instructional strategies in their teaching processes. In all constructivist learning environment, teachers use individual difference to lay the basis upon which students can make meaning of new knowledge (Tetzlaff, 2009).

Torre et al. (2006) viewed behaviourist instruction as most important in instructing students when an educational intervention is aimed at change in behaviour. This is because behavioural instruction strategies stress on students' mastery of prerequisite steps ahead of the subsequent steps. In the behaviourist learning environment, teachers mainly arrange the environment to obtain feedback from students. Osborne (1993) explained that as much as over reliance on didactic teaching and learning strategies was not good enough for all students so as over reliance on constructivist strategies such as co-operative and discussion-based activities for meaning making could not be good enough for all students. Student motivation and preferred learning strategies differ from student to student and therefore it is not appropriate to centre teachers' teaching strategies on only one learning theory. Such teaching and learning processes could satisfy the need of some group of students whereas others suffer.

Osborne (1993) further reported that students differ in their interest and that there is no single, effective teaching strategy for teaching and learning of concepts (Landcare Research, 2002). And that a single instructional strategy for science education is inappropriate as students have to develop scientific concepts over a spectrum of instructional strategies. Brown (2005) was of the view that teachers' teaching practices in either the domain of constructivist learning theory or behaviourist learning theory cannot be considered as entirely right or wrong. Cooperstein and Kocevar-Weidinger (2004) therefore suggested that in preparing lessons, teachers have to consider merging a number of learning theories that can be used to enhance students' transferability of knowledge which in effect will help students make meaning of concepts.

"In general, high quality constructivist teaching requires more support, more access to resources, more careful design and attention to detail, more progress monitoring, and more carefully craft guidance than traditional instructor-led teaching" (Wilson, 2010, p. 5). Tetzlaff (2009) reiterated that constructivist learning theory does not eliminate teachers entirely from assisting students. That is the traditional role of teachers as information presenters should give way to teachers' role as facilitators in the teaching and learning process (by asking questions, making suggestions, and explaining concepts) in the perspective of constructivism. Notwithstanding the fact that students are responsible for their meaning making under constructivism, teachers are to create opportunities to facilitate student learning (Taber, 2011; Tetzlaff, 2009). According to Tetzlaff (2009), an introduction of teachers' intervention into constructivist learning environment is very necessary in order to prevent students from developing misunderstanding of the new material and to ensure that students work towards the lesson objectives. In constructivism the role of teachers is to facilitate the teaching and learning process (Brown, 2005; Wilson, 2010).

Cooperstein and Kocevar-Weidinger (2004) suggested that in using constructivist instructional strategies, teachers must conduct 'needs assessment' of the content of the session and put structures in place that will safe guard the skills and concepts students are expected to acquire at the end of the limited short period lessons. The structures are what Vygotsky referred to as scaffoldings which guide and support students to make meaning of concepts. That is teachers must lead students to make meaning of concepts.

Brown (2005) proposed that beyond constructivism through the path of social constructivism, instructional strategies will be in the area of navigation, evaluation, integration, problem solving, and communication. Here teachers are coaches to students on how to navigate.

From Taber (2011, p. 44), "... all meaningful learning is a process of personal meaning making through that individual's current knowledge and understanding." This is to say that individual students make personal meaning of whatever is taught in the classroom in their own respect (Cooperstein & Kocevar-Weidinger, 2004). Notwithstanding the fact that students make different versions of meaning of what they are taught by teachers, Taber (2011) asserted that a proportion of students make similar meaning of such concepts in line with the intended objectives of lessons.

From Ausubel's point of view, meaningful learning occurs when students are able to create linkages between new information and existing knowledge (Torre et al., 2006). This is because in constructivist lessons, students make meaning of new material by linking the new material to previous experience and knowledge (Cooperstein & Kocevar-Weidinger, 2004).

Cooperstein and Kocevar-Weidinger (2004) suggested that to take advantage of constructivist learning theories teachers must provide students with opportunities of reflecting on concepts (Hein, 1991). This is because Torre et al. (2006) found that reflection is one of the important attributes of cognitive learning theory. Students are provided with the opportunity to make meaning of situation after it has occurred or as the process unfold. Students make meaning from the experiences through critical reflection. Teachers' role in constructivism is to facilitate students' critical reflection of experiences. According to Ernest (2010), individual student makes meaning of signs and see them as appropriate with respect to the individual's experience of the public use of the signs. Students individually reflect on such experiences of the use of signs and imitate their use.

From constructivist point of view, meaning making is not an instantaneous process but students learn new concepts through reasonable period of time. This reasonable period of time allows students to reflect on the new material which enhances meaning construction (Hein, 1991). According to Cooperstein and Kocevar-Weidinger (2004), reflection is also necessary for teachers as it is for students. That is teachers' reflection serves a guide for instructional planning as teachers are their own best or worst critics.

Constructivist learning theories are inductive oriented in nature. That is students' meaning making only occurs after experience (Cooperstein & Kocevar-Weidinger, 2004; Landcare Research, 2002) and students experience the surroundings through the processes of interpretation (Taber, 2011) and the new knowledge is constructed as a result of assimilation of new experiences of the world and modification of the students' previous knowledge (Landcare Research, 2002). Constructivist instructional strategies therefore provide students with opportunities that create cognitive conflict between students' previous knowledge and experiences and the new information. This cognitive conflict promotes students' conceptual development (Jones & Brader-Araje, 2002).

Lowenthal and Muth (2008) advocated that though constructivism is a theory of teaching but teachers' instructional strategies should focus on the importance of context (Hein, 1991), authentic problems and tasks, discovery learning, student's prior knowledge, group projects and discussion, student choice, and authentic assessment. Such instructional strategies are anchored instruction, situated learning, and cognitive apprenticeship. Anchored instruction is that learning which involves lodging instruction in an authentic problem-based story, case study, or situation where students generate and test possible solutions to problem; situated learning is that learning which involves social interactions and collaboration in authentic contexts; and cognitive apprenticeship is that learning which takes the form of traditional apprenticeship. These forms of instructional strategies developed out of constructivist learning theories make students active and use their previous experiences (Lowenthal & Muth, 2008).

Lowenthal and Muth (2008) reiterated that notwithstanding an adoption of constructivist learning theories in informing teachers' selection of instructional strategies, teacher-centered instructional strategies cannot be excluded entirely as they are all about meaning making when it comes to learning and knowledge. However, constructivism is not rigid about teachers' input during the teaching and learning process as discovery learning or direct instruction is dependent on the specific learning activities and concept (Taber, 2011). From Richardson (2003, p. 1628), "direct instruction and lectures may still be part of a constructivist classroom." This is because students make meaning from any transmission model of teaching activities such as direct instruction and even from non-interactive media.

The major role of teachers in a constructivist lesson is to 'arrange the conditions of learning'. That is teachers have to plan carefully in order to design activities for students to make meaning. Teachers must used examples and activities to lead students to the required knowledge. The use of sufficient examples enhances concept formation and the choice of activities also enhances the quality of meaning making (Cooperstein & Kocevar-Weidinger, 2004). Teachers must also motivate students to appreciate why they need to learn the new material as this will help facilitate students learning (Hein, 1991).

Teachers' view of nature of knowledge influences the selection and use of instructional strategies. It is therefore important for teachers to appreciate whether knowledge is independent of us or not. From Hein (1991), constructivist learning theories believed that knowledge is not independent of students and that students have to construct meaning for themselves as they learn. Teachers should understand the world, organise it in the possible rational way and present it to students for them to manipulate the objects of the world.

Hendriks, Luyten, Scheerens, Sleegers, and Steen (2010); Richardson (2003) found that teachers' deep and strong content knowledge is a necessary tool in a constructivist classroom. However, teachers' instructional strategies, learning to learn and reflection on the strategies are equally important in constructivist lessons (Hendriks et al., 2010). This is because such teachers could provide students with opportunities to develop deep understanding of concepts, internalise the concepts, understand the nature of development of knowledge, and develop complex cognitive structures for connections to other bodies of knowledge.

Wilson (2010) identified several benefits from constructivism. These include the fact that it corresponds to how students really learn; the outcomes of constructivist instruction are high-order thinking; it integrates emotions, affects, and engages discussions of learning and cognition; and it is applicable to out-of-classroom needs. Torre et al. (2006) found that under constructivism students form knowledge from integration of learning activities and experiences into knowledge. Wilson (2010) stressed that constructivist learning theory is appropriate for all teachers and students at all levels of education and training. However, some attributes of constructivist learning theory are excluded in some teaching practices because of its lack of specificity.

The prior knowledge of student in concepts is very important for students in learning new concepts. Hence, teachers need to adopt instructional strategies that will actively engage students mentally to confront any misconceptions and reflect accurate meaning making (Kruse, 2009). Mundry (2005) explained that from cognitive constructivism, students are said to build knowledge upon the previous knowledge. There is therefore the need to take advantage of such previous knowledge by using diverse experiences to add to and to challenge such previous knowledge.

Cooperstein and Kocevar-Weidinger (2004) found that during constructivist lessons, students build on concepts through activities. The activities assist students make meaning of abstract concepts, transfer such concepts, and retain them. Students further learn as they engage in activities which are carefully selected to resemble real life situations (referred to as authentic tasks).

Instructive instruction includes problem-based learning, anchored instruction, cognitive apprenticeship, intentional learning environment, and REALs, which is rich environment for authentic learning, (Wilson, 2010). The constructivist learning theories provide teachers at all levels of education as well as all subjects/courses with sound theoretical basis for selection of instructional strategies (Taber, 2011). The current study therefore adopted constructivism as theoretical framework because constructivist instructional strategies enable students to discover concepts, develop skills, make meaning of abstract concepts, transfer and retain concepts (Cooperstein & Kocevar-Weidinger, 2004).

Pedagogical Content Knowledge

Pedagogical content knowledge (PCK) is a concept that was introduced by Lee S. Shulman in one of his papers titled: "Those who understand: knowledge growth in teaching" presented at American Educational Research Association, Chicago (Shulman, 1986). The criticism of Shulman (1986) on the sharp distinction between subject matter mastery and teachers' pedagogical skills resulted in the concept of PCK. PCK describes the knowledge of content that enables teachers to develop and use tools for effective teaching and learning. Shulman (1987) further explained that the boundaries of PCK extend beyond teachers' knowledge of subject matter to areas of content knowledge of teaching.

`Shulman (1987) asserted that PCK makes use of the combination of content and pedagogy to develop understanding of how specific topics, problems, or issues are organised for instruction, representation, and adaption to the needs of variety of students. Mishra and Koehler (2006) asserted that PCK came in as a Shulman's advanced thinking with respect to teacher knowledge and thereby proposing that there is a relationship between teachers' content knowledge and pedagogy. The content knowledge, according to Mishra and Koehler (2006), is the actual subject matter to be taught and pedagogical knowledge is the processes and practices of teaching and learning such as student learning, classroom management, lesson plan development and implementation, and student evaluation.

Hendriks et al. (2010, p. 23) asserted that "PCK is about selection of topics, useful forms of presentation, analogies, illustrations, examples, explanations, and demonstrations". Wilson and Peterson (2006) viewed PCK as an area that allows teachers to understand how best to presents students with knowledge they seek understanding or proficiency. PCK can also be considered as teachers' knowledge and beliefs relating to the purpose of teaching particular topics and teachers' knowledge of curriculum materials available for instruction (van Driel, Verloop, & de Vos., 1998). A teacher instruction represents PCK when it connects the how, why, and what of the subject matter to be taught with students who are to learn that subject matter (Mulhall, Berry, & Loughran, 2003). From van Driel et al. (1998, p. 6740), PCK is a craft knowledge, which is described as:

> integrated knowledge which represents the teachers' accumulated wisdom with respect to their teaching practice. As this craft knowledge guides the teachers' actions in practice, it encompasses teachers' knowledge and beliefs with respect to various aspects such as pedagogy, students, subject matter, and the curriculum.

In addition, PCK is the teachers' interpretations and transformation of subject-matter knowledge in the context of facilitating student learning. When the subject matter is transformed, it can be used effectively and flexibly in the interactions amongst teachers and students in the teaching and learning process (van Driel et al., 1998). Transformation in Shulman's scheme of PCK is that kind of explanations which effective teachers make as they transform subject matter knowledge to the level and specific characteristics of their respective students.

According to Bond-Robinson (2005), this kind of explanations is termed as transforming explanation and the nature of transforming explanations is dependent upon the academic disciplinary subject matter. “A transforming explanation is a chemistry-specific illustration of how chemists think about a chemical process, which is linked by the explanation to students’ thinking of that same chemical process” (Bond-Robinson, 2005, p. 94). Chemistry teachers explain the chemical concepts by using atomic, kinetic theories, and thermochemistry. An individual student can make meaning of chemical reactions by relating the visible chemical change with mental models of atoms, ions, and molecules interactions in a nanoscopic world.

According to Bond-Robinson (2005), chemistry teachers can transform nanoscopic explanation by making known to students the importance of objects and materials in the environment; pictorially illustrating the macro mechanical system as it occurred or will occur; writing chemical symbols to represent everything occurred in the chemical process; and introducing the mathematical relationships among variables to establish cause and effect and to quantify the chemical process. This approach helps chemistry teachers to systematically generate transforming explanation any time a new content is presented.

Students make meaning of chemical concepts through explanation and teachers are required to show to students how to reason like chemists. Chemists are known to reason via variety of representations. Bond-Robinson (2005, p. 97) therefore reported that

> Teaching students the representations of chemistry is getting

> students to 'see' things in motion the way chemists do. Teaching science as static facts or static models requires little in the way of reasoning. Therefore, transforming explanations made to students in chemistry often involve mechanical reasoning of sequence of cause and effect relationship in chemical processes with theoretical objects or in a mechanical system built with macroscopic objects.

Hence, transforming subject matter for teaching is the pivotal point of PCK (Mishra & Koehler, 2006).

From Shulman's (1987) work, it could be seen that the main characteristic feature of the knowledge base of teachers is the meeting point of content and pedagogy, the ability to transform content knowledge into forms that are pedagogically powerful and yet could be used to benefit students notwithstanding the differences in abilities and background. Mishra and Koehler (2006) emphasized that PCK is an intersection of subject matter and pedagogy and not just a simple consideration of subject matter and pedagogy.

van Driel et al. (1998) found that all authors agreed that teachers develop PCK through an integrative process rooted in the teaching and learning process. According Wilson and Peterson (2006), PCK is acquired by teachers through teaching practices. Teachers can generate their own PCK through their own teaching practices such as analysing specific students' learning difficulties and through professional development programmes such as in-service training on student conceptions. The combination of science teachers' familiarity with a specific topic and teaching experiences contributes positively to teachers' development of PCK. Science teachers' general pedagogical knowledge was found to be an element that could be considered as a supporting framework for the development of PCK (van Driel et al., 1998).

Mulhall et al. (2003) found that there is no universal conceptualisation of PCK. As teachers' development of PCK is embedded in the classroom, beginning teachers and experience teachers have little or no PCK in specific topics that they have never taught (Mulhall et al., 2003; van Driel et al., 1998). Teaching experience then is the major source of PCK and teachers' knowledge of content to be taught is a prerequisite of PCK (van Driel et al., 1998).

Mulhall et al. (2003) explained PCK as a special aspect of knowledge that teachers possess with respect to teaching specific subject matter to particular group of students to enhance their understanding. However, there is little to be said about research works relating to science teachers' PCK in the area of teaching specific topics (Mulhall et al., 2003; van Driel et al., 1998). To avoid reinventing the wheel as proposed by van Driel et al. (1998), specific PCK must be developed. Mulhall et al. (2003) then studied science teachers' PCK with respect to chemical equilibrium and found that teachers' subject matter knowledge could improve by studying PCK in relation to specific topics which is potentially valuable contributions to teachers' knowledge base of instruction.

Mulhall et al. (2003) reported that 'successful' teachers in a given subject matter promote students' meaning making. This is because such teachers could have developed well-grounded PCK in such subject matter. Topic specific PCK will help successful teachers' thinking in the context of teaching such a particular scientific subject matter. This is because there will be an evidence that such teachers are using their PCK.

Topics specific PCK in science-related subjects or courses could be developed base upon three considerations. These are effective science teaching and learning; the complicated nature of teacher thinking; and ways of enhancing understanding of teaching experiences of teachers (Mulhall et al., 2003).

From Bucat (2005), content knowledge is the individual's understanding of the subject matter and pedagogical knowledge is the individual's understanding of the teaching and learning processes independent of the subject matter. There is distinction between a teacher's knowledge of the topic (content knowledge) and a teacher's knowledge of the teaching and learning of that topic (pedagogical content knowledge). Pedagogical content knowledge according to Bucat (2005) therefore is the knowledge about the teaching and learning of particular topic with which learning demands are inherent in the subject matter.

van Driel et al. (1998) identified teachers' knowledge of presentation of subject matter and teachers' meaning making of students' learning difficulties and conceptions as the main domains of PCK. These two domains of PCK are interrelated and should be used flexibly. van Driel et al. (1998) reported that a number of authors have added some domains to the two main domains identified by Shulman in the 1986; and that there is no universally accepted conceptualisation of PCK. For instance, Cochram, DeRuiter, and King identified pedagogy, subject matter content, student characteristics, and environmental context of learning as the domains of PCK and Fernandex-Balboa and Stiehl identified subject matter, the students, instructional strategies, the teaching context, and teachers' teaching purposes.

Godino, Batanero, Roa, and Wilhelmi (2008, p. 1) identified five components of PCK as epistemology, which is reflection on the meaning of subject matter to be taught; cognition, which is prediction of students' learning difficulties, errors, obstacles, and strategies; and teaching resources and techniques, which is experience with good examples of teaching situations, didactic tools, critical capacity to analysed textbooks, curricular documents and to adapt such skills to different teaching levels. The rest are affect, which is the capacity to engage students' interest and to take into account the students' attitudes and beliefs; and interaction, which to create good classroom communication and assessment to guide instruction. van Driel and his colleagues were quick to add that notwithstanding the lack of universality of the concept of PCK, all other authors agreed on the two domains of Shulman's PCK (van Driel et al., 1998).

Verloop asserted that the purpose of PCK is to facilitate development of PCK by pre-service teachers. This will help to eliminate the possibility of pre-service teachers reinventing the wheel (van Driel et al., 1998). With respect to such knowledge of the particular content the teacher is teaching, the content is made easy or difficult to students (Shulman, 1986; van Driel et al., 1998). Shulman (1987) asserted that specific subject matter and instructional strategies interact in the minds of teachers. Every instruction demands some basic skills, subject matter, and general pedagogical skills from teachers. Teachers' understanding of subject matter is vital to inquiry lessons. Mishra and Koehler (2006) added that teachers with an in depth pedagogical knowledge understand how students constructs knowledge.

Bond-Robinson (2005) explained that teachers gain craft knowledge through previous education, personal background, teaching context, and teaching experience. Teachers then demonstrate effective behaviour as a result of their wisdom of craft knowledge. PCK enables teachers to interpret students' understanding of concepts and design and develop activities that help students to explore concepts and hypothesize, and support students' discussion towards a shared understanding (Richardson, 2003). PCK helps teachers to adopt instructional strategies that enable them use appropriate conceptual representations to address students' difficulties in order to foster meaningful understanding (Mishra & Koehler, 2006). Agyei and Voogt (2012) appreciated that Shulman's PCK brought to the forth the need for teachers to learn about the number of possible means of teaching content. Hence, teachers' instruction can be influenced by the theories of learning and Mulhall et al. (2003) study of formulation of PCK by teachers was influenced by the constructivist learning theory.

From Shulman (1986, p. 9), PCK "is the ways of representing and formulating the subject that make it comprehensible to others" and according to Mishra and Koehler (2006, p. 1027), "PCK is concerned with the representation and formulation of concepts, pedagogical techniques, knowledge of what makes concepts difficult or easy to learn, knowledge of students' prior knowledge, and theories of epistemology." From the two descriptions, it can be explained that majority of the forms of representations such as analogies, illustrations, examples, explanations, and demonstrations are ways of representing and formulating subject matter to make it understandable to students (Shulman, 1986).

According to van Driel et al. (1998, p. 675), "the more representations teachers have at their disposal and the better they recognise learning difficulties, the more effectively they can deploy their PCK." With PCK, teachers make meaning of students' learning difficulties and preconceptions (van Driel et al., 1998). An insight of a teacher into students' potential difficulties in relation to teaching a specific topic is an important attributes of the teacher's PCK (Shulman, 1986). For example, Bond-Robinson (2005) reported that graduate teaching assistants develop PCK as they work through the challenges associated with teaching chemistry laboratories that help to interact with students and teach chemical concepts.

Mulhall et al. (2003) concluded their report by saying that they are in agreement with Bullough that in exploring critical aspects of PCK and their possible division amongst pre- and in-service teacher education, there is the need to answer question involving 'a unique quality of scholarship'.

Teaching and Learning Strategies

According to Herod (2012, p. 6), "learning is the cognitive/physical/affective acquisition and processing of skills/knowledge to varying depths, (where 'depth' refers to one's understanding of, ability to manipulate, apply, and/or communicate the skill/knowledge)." Learning is a process where students make meaning of new concepts by linking them to the current conceptual framework (Kruse, 2009). Kelly (2001) asserted that learning is an adaptive change in students' behaviour or belief. From constructivists' point of view, learning is self-regulated with promising avenues for students to discover and to interpret findings from such discoveries (Hendriks et al., 2010).

Wilson and Peterson (2006, p. 1) built their write up around three dimensions of learning as "that learning is a process of active construction; that learning is a social phenomenon, as well as an individual experience; and that learner differences are resources, not obstacles". Students' active involvement in learning process is an important attribute as Wilson and Peterson (2006) explained that constructivists share the view that students actively make meaning from the test they read, from interacting with their surroundings, and from sharing ideas with others. Felder (1993) explained that active students construct knowledge very well whenever they work in groups. The group work should not be limited to classroom works only but to out of classroom exercises as well.

Kruse (2009) stressed that the fact that constructivists believed that students actively make meaning of concept does not mean that the role of teachers is insignificant. For instance, scientific knowledge cannot be acquired by instinct and that the teachers' intervention in the form of scaffolds (such as questions) to aid students' learning cannot be under estimated. An active learning environment is the one which is student-centered [that is where students are supported to construct their own meaning of concepts]; knowledge-centered [that is where instructions are geared towards content as the most important for students learning]; assessment-centered [that is where structures are put in place to continuously assess students' learning and provide feedback]; and community-centered [that is where provision is made for continuous students' interactions in the learning process] (Mundry, 2005).

Every student in learning situation goes through processes of change to support behaviour change and the processes of change and its addend reversion could occur a number of times ahead of any change in behaviour. According to Landcare Research (2002), behaviour change could be equated to knowing what to do, creating enabling environment, and being motivated and that "approaches to facilitate behaviour change are most effective when used to enhance constructivist or learner-centered instructional strategies because they emphasize interactivity, and learner control and engagement" (Landcare Research, 2002, p. 17).

Landcare Research (2002) explained that behaviour change is not necessarily an individual learning activities but a social process as well. There is therefore the need to consider both individual and social factors that have potential of influencing students' construction of new knowledge of the world they live in. An attempt to create a balance between individual and social factors is subject to the individual student concerned and the action taken.

It is worth noting that change in behaviour is different from one student to another and that such change cannot occur in just a single step (Landcare Research, 2002). The various stages of change in behaviour are influenced by the environment. Thus, conducive environment is a pre-requisite for change in behaviour of students. Students normally adapt and improve such conducive environment through individuals and social groups (Landcare Research, 2002).

Herod (2012) suggested that it is necessary to consider learning as a continuum (from non-reflective learning to reflective learning); with a lot of points of interest on this continuum. Factors such as curriculum materials, objectives, and learning styles of students contribute to the level where students should be learning at. In addition, to achieve effective student learning in course or subject, teachers must adopt teaching strategies that move along the continuum of directed learning to facilitated learning. In directed learning there is little opportunity for students to be engaged in reflective thinking as oppose to facilitated learning where students are independent and have the opportunity to be engaged in reflective thinking (Herod, 2012).

Kruse (2009) asserted that the developmental cognitivists' view of students learning from concrete operational to formal operation with respect to their year should be rather seen as a continuum. Kruse explained that students may be concrete operational under some concepts and formal operational in other concepts. Herod (2012) advanced a point that if students' learning is a continuum, then teachers' teaching strategies must be in agreement with that continuum. That is teachers must select strategy or strategies from a spectrum of teaching strategies for effective students' learning. At supposedly midway of the continuum of learning from directed to facilitated learning is characterised by guided discussion, group work, and problem-based learning.

Felder (1993) classified students' learning style into sensing and intuition and reiterated that sensors are at the disadvantage in learning scientific concepts especially in chemistry and physics. This is because most scientific concepts are presented in abstract form using theories and formulae. Difficulties associated with students' learning of science could be reduced and students' understanding in scientific concepts enhance if teachers can modify their teaching strategies to suit students' learning strategies. Felder (1993) therefore recommended that in order to meet students' needs in science lessons teachers should systematically adapt to the use of a fraction of additional instructional strategies in their lessons.

Felder (1993) identified that most students have deeper understanding of and longer retention of new knowledge when it is acquired through induction. That is where students are exposed to conceptual problems, given the opportunity to solve the problem on their own, and helped to identify and understand the mistakes made as they attempt to solve problem. Teaching strategies of teachers have influence on students' retention and use of concepts they are taught. That is students whose learning strategies are in consonance with the teaching strategies of their teachers tend to retain and use the new knowledge very well. Such students further show positive attitudes towards such teachers and the subject or courses they handle. The vice versa is also true (Felder, 1993).

Wilson and Peterson (2006) found that there is increasing knowledge of the role of social groups in knowledge development in the current literature on theories of learning. That is psychologists today are aware of the significant contribution of social groups in knowledge construction. Social learning theory has evolved with names such as Social Constructivism, Sociocultural Theory, or Activity Theory. Notwithstanding the differences in the names assigned to social learning theory by the different proponents, there are points of convergence. Social learning theories share the view that knowledge is constructed when students practice what they learn. That is knowledge construction cannot be separated from practice (Wilson & Peterson, 2006).

All social learning theorists share the view that learning is basically a social phenomenon which occurs within our communities; individual student performance should be assessed base on the true participation of the individual in the activity and that the reward of performance should be determined by the members of the group (Wilson & Peterson, 2006); and meaning making is context specific (Bonk & Cunningham, 1998; Wilson & Peterson, 2006). Based on the fat that social phenomenon occurs within our communities, Wilson and Peterson (2006) explained that meaning making of concepts is dependent upon the interactions among individuals in their communities (such as the classroom) and their participation in activities. There is therefore collaboration in learning through participation.

To support students to make meaning of concepts through peer or greater social interactions, teachers must choose instructional strategies that will enable students to collaborate. That is students must collaborate in order to push and support each other to learn (Kruse, 2009). General class discussion should employ collaborative learning environment but not where the teacher becomes the centre of attraction in the teaching and learning process. Consequently, in such class discussion teachers actively ask follow-up questions, provide information, prevent individual student dominance, and maintain focus. Kruse (2009, p. 6) said:

> Rather than being concerned with my students 'learning style,' I will make much better use of my own mental effort and planning by considering students developmental stage, prior experience, initial conceptions and the manner in which the content is best presented.

Wilson and Peterson (2006) emphasized that teachers cannot assume only one role in presenting instructional materials to students. That is teachers should as matter of importance use different instructional strategies in teaching as and when necessary. Teachers have to identify students with the characteristics that will facilitate the process of teaching and learning. That is teachers have to take advantage of the potentials of students and use such potentials in forming teams where the talents could be of benefits to the group members. Kruse (2009) added that the communities (that is the social learning environment) within which students learn assist in shaping the conceptual framework for meaning making. That is the role of teachers, parents, and peers in shaping the conceptual framework of students for meaning making cannot be over emphasized. It must be noted that "without the interactions of peers, parents, and teachers, many students would not be encouraged to extend their range of understanding" (Kruse, 2009, p. 3).

Wilson and Peterson (2006) asserted that students need to be provided with opportunities that could assist them to learn in a number of ways. Teachers should therefore select their teaching strategies from diversity of learning theories. There is therefore no need of alienating instructional strategies which are behavioural oriented in favour of instructional strategies which are in the realm of constructivism (Brown, 2005; Wilson & Peterson, 2006). This is because students' learning needs more than one learning theory (Bednar, Cunningham, Duffy, & Perry, 1995; Landcare Research, 2002; Osborne, 1993; Wilson & Peterson, 2006). From this assertion, Wilson and Peterson (2006) noted that learning theories vary in quality and rigor and that teachers usually interpret, adapt, and combine such theories in their teaching practices.

Though the use of varied instructional strategies with roots from behaviouralists and constructivists perspectives is said to be probable but Wilson and Peterson (2006) pointed out it should not be 'anything goes'. Teachers have to select instructional strategies with respect to lesson's objectives, the students, and the content as no single instructional strategy can be good enough for all students in each subject or course for every day (Bednar et al., 1995; Cooperstein & Kocevar-Weidinger, 2004; Wilson & Peterson, 2006). According to Wilson and Peterson (2006), "strategies ought to be selected thoughtfully, varied in their approaches, and refined over time through reflection" (p. 11).

Teachers teaching practices change in the light of changes in teachers' understanding of teaching and learning processes (Brown, 2004). Bednar et al. (1995) indicated that any strategy of teaching must be related to theory of learning and cognition. And that a designed technique of teaching should not be based upon a single theory of learning. Bonk and Cunningham (1998, p. 26) asserted:

> "If learning is predominantly information processing, then instruction should provide for efficient communication of information and effective strategies for remembering. If learning is predominantly experiential growth, then instruction should focus on experiences and activities that promote the individual development of the appropriate cognitive networks or mind maps. And finally, if learning is predominantly a sociocultural dialogic, then instruction should provide opportunities for embedding learning in authentic tasks leading to participation in a community of practice.

From Hammond et al. (2001), learning strategy could be termed effective only and only if the strategy depends upon the outcome preferred and where the teaching and learning process is heading towards. Kruse (2009) emphasized that for effective instruction, instructional strategies which are behavioural oriented should be used alongside instructional strategies from the realms of cognitive theories.

Concept of Design-Based Research

The research approach for the study was design-based research, which was situated in the context of the relaxation of design, development, and evaluation of an intervention for teaching oxidation-reduction reactions (Keppell, Au, Ma, & Chan, 2005; Richey & Klein, 2005; Richey & Nelson, 1996). In the current literature, various researchers have identified different names for design-based research. Examples of such names include Design Studies, Design Experiments, Design Research, Development Research, Developmental Research, Formative Research, and Engineering Research (Andriessen, 2006; Plomp, 2010; Wang & Hannafin, 2005). Notwithstanding the numerous and varying names assigned to design-based research, the basic principles and techniques have been identified as same to all (Wang & Hannafin, 2005).

Visscher-Voerman and Gustafson (2004) reported that there are four paradigms for the conduct of design-based research which are not definitely mutually exclusive. These paradigms are instrumental, communicative, pragmatic, and artistic.

Under instrumental paradigm, designers specify their goals and outcomes of the product to be designed at the beginning of the process. That is there should be consistency in the relationship among the goals, learning situations and processes, and outcomes of the design. To begin with in instrumental paradigm, there is exploration and formulation of intended outcomes, later translated into concrete product goals and measurable objectives. The later stages of the process are used for choosing and designing means to reach the concrete goals and objectives that result in a blueprint of the product. Instrumental paradigm uses less number of evaluation activities in the design process as compared to other paradigms (Visscher-Voerman & Gustafson, 2004).

Under the communicative paradigm, a good design should be the one agreed upon by the designers and other stakeholders. The beginning of the design is much of decision making based on negotiations among all stakeholders but not needs analysis of existing situation. That is there is formulation of 'platform of ideas' from stakeholder negotiations leading to recognition of the problem, material constraints, basic pedagogical or psychological premises, and tentative concept of product. Design guidelines are deduced through views of stakeholders on the product, process, and successive versions of the product (Visscher-Voerman & Gustafson, 2004).

Under pragmatic paradigm, processes of designing, try-outs, and revisiting a number of prototypes are involved. During the process of prototyping, the end users are involved in the try-outs. Pragmatic designers derive satisfaction from the effectiveness of their products and effectiveness is ascertained through try-outs with end users. Pragmatic paradigm is characterised by formative evaluation and its iterations and revisions of prototypes (Visscher-Voerman & Gustafson, 2004).

Under artistic paradigm, designers assert that design process cannot be planned but designers' experiences and expertise are the driving forces. This implies that design guidelines are drawn base on designer's insight. Artistic designers assumed that reality is constructed by individuals and their subjective evaluation is the basis for judging products as good (Visscher-Voerman & Gustafson, 2004).

According to Visscher-Voerman and Gustafson (2004), design-based research approaches are personal and the selection of a particular paradigm is the preference of the designer. However, in the current study, the assumptions in relation to pragmatic paradigm formed the basis of using design-based research approach.

Wang and Hannafin (2005, p. 6) gave a comprehensive description of design-based research as "a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories." Another detailed description given by Plomp (2010, p. 4) is

> educational design research is the systematic study of designing, developing, and evaluating educational interventions (programmes, teaching-learning strategies and materials, products, and systems) as solutions for complex problems in educational practice, which also aims at advancing our knowledge about the characteristics of these interventions and the processes to design and develop them.

The two descriptions of design-based research give an indication that it is systematic in addressing complex problems in education but there are no laid down guidelines for arriving at the solution (intervention), and hence its iterative nature in terms of developing the solution. This is to say that design-based research is more appropriate when the problem under study is open and 'wicked' with initial statement of the problem uncertain (Kelly, 2010; van den Akker, 1999). It is also evident from the two descriptions of design-based research that theory formulation is one of the by-products (Plomp, 2010; van den Akker, 1999; Wang & Hannafin, 2005).

According to van den Akker, Gravemeijer, Mckenney, and Nieveen (as cited in Anto, 2013), design-based research could be described simply as intervention, iterative, process, utility, and theory oriented. It is intervention oriented as it is aimed at designing interventions; it is iterative oriented as it is cyclic in its approach; it is process oriented as it is centered on understanding and enhancing interventions; it is utility oriented as its merits are built upon the fact that the interventions is practically tested; and it is theory oriented as the design is based upon theory and leads to theory development (Anto, 2013).

From the description of the design-based research, it could be appreciated that the design is cyclical in nature involving analysis, design, evaluation, and revision strategies till much more convincing result is attained (Andriessen, 2006; Ottevanger, 2001; Plomp, 2010; van den Akker, 1999). The developmental cycle of design-based research is in agreement with that of Keppell et al. (2005) which was adapted from Reeves and used in their study. Figure 1 shows the cyclic outline of design-based research in the view of Reeves (2006).

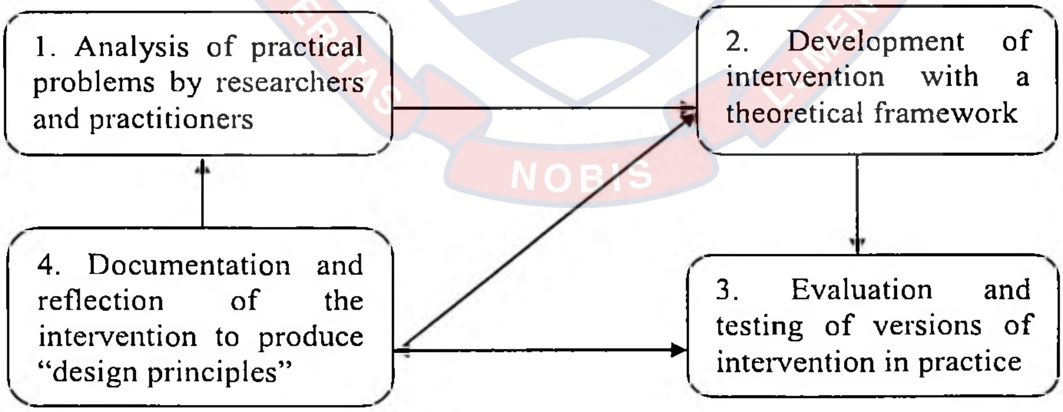

Figure 1: Cyclic stages of design-based research adapted from Reeves.

According to Reeves (2006), each stage of a design-based research provides the researchers and the practitioners with feedback. The feedback from every stage of the design could be seen to be used to improve upon the quality of the intervention. The act of improving the quality of the intervention is actualised by revisiting initial aspects of the development of the intervention where necessary with the meanings so deduced from the feedback by the researchers and the practitioners. It will be both forward and backward processes in the development of the intervention, which could be appropriated as the solution to the identified educational problem. Richey and Klein (2005) then explained that the evaluation process of a design-based research involves formative and summative processes together with confirmative process. These evaluation processes are to help to identify the strength and weakness of the intervention and to help improve the quality of its use in solving the identified educational problem. However, formative evaluation is the most visible landmark of the research activities under design-based research (Plomp, 2010). This is because formative evaluation is central to the processes involved in design-based research. The purpose of formative processes is to provide the development with the necessary information needed to feed the cycle of analysis, design, evaluation, and revision (van den Akker, 2010). The fourth stage of the developmental cycle of design-based research as seen from Figure 1 is the documentation of the principles involved in designing and development. The design principles could be realised by reflecting upon the four stages of the design-based research. van den

Akker (1999) asserted that during design-based research works, the processes of systematic reflection and documentation usually lead to establishment of theory.

Plomp (2010) also identified the stages of design-based research as preliminary research phase, prototyping phase, and assessment phase. According to Plomp, the processes involved in the preliminary research phase include needs and context analysis, review of related literature, and analysis of curriculum materials, which in totality contribute to the establishment of conceptual framework of the study. The iterative cycles of the design and development of intervention to the identified educational problem are carried out at the prototyping stage of design-based research. Nieveen (2010) explained that the iterations help to improve the intervention under development and the tentative design principles. The prototyping phase is built basically on formative evaluation and reflection. This is because there is high possibility of having the intervention failing at its first implementation, hence the need for revision of some aspects of the intervention (Antwi, 2013). The iterative nature ensures that satisfying balance is achieved between the intended and the realisation (Plomp, 2010). At the assessment phase of design-based research, summative evaluation exercises are carried out to ascertain the quality of the intervention. Kelly (2010) explained that in design-based research, assessment is not necessarily targeting summation of students' learning. It is however a must as researchers should not be only interested in iterative investigation of the impact of prototyping but to address the issue of how the impact will be measured. That is the quality of the intervention is the measure of how successful the intervention is with respect to the predetermined specifications. It should be noted further that the outcomes of the summative assessment are often used to improve upon the quality of the intervention (Plomp, 2010).

Nieveen and her colleagues in their work identified all the three stages (preliminary, prototyping, and assessment) of design-based research of Plomp (2010) in addition to systematic reflection and documentation stage (Nieveen, McKenney, & van den Akker, 2006). The added systematic reflection and documentation stage is not just a stage in the cyclical design-based research but an ongoing activity that occurs at all cycles during the research work. It was noted by Andriessen (2006) that the process of reflection helps to assess the success of an intervention and the possibility of improving the intervention. However, researchers usually go into retrospection at the end of the research work to analyse and specify the design principles (Nieveen et al., 2006). Thus, in design-based research process, the findings and any changes so made are documented; and findings are further linked to the process and setting of the design (Wang & Hannafin, 2005).

From Plomp (2010), design-based research basically focuses on designing and developing interventions in fieldworks and the question is: when is design-based research most appropriate in educational research works? It is most appropriate in educational research where a single study usually fails to provide the research community with a solution to an identified complex problem (Mckenney & Reeves, 2012; Walker, 2006); when the pedagogical content knowledge of the teachers (practitioners) involved is poor; when a solution to an identified educational problem will result in learning to the researchers and practitioners; and where the outcome of the research work could minimise significantly the malfunction in the educational system (Kelly, 2010). It is also most appropriate to use design-based research when there is the need to evaluate the intervention as well as the processes involved in design and development of the intervention (Antwi, 2013); when there is the need to find realistic solutions to research questions (Agyei, 2012); when governments have the need to come out with challenging educational reforms with great impact in the future (Plomp, 2010).

The purpose of using design-based research for the study in part is to help create a linkage amongst research and practice (Romme, 2003); make practical and scientific contributions (van den Akker, 2010) to chemistry education; offer researchers no constraints of the basic research/applied research dichotomy (Keppell et al., 2005); and enhance the professional development of the pre-service teachers involved in the study (Andriessen, 2006; Plomp, 2010; Romme, 2003) in the area of chemistry education. Another reason for adopting design-based research for the study is to integrate conceptions of designers into the development of instructions or products which are tested in the classroom settings (van den Akker, 2010); help the researcher who has assumed the role of designers to use existing knowledge to design and develop an intervention to problems facing the teaching and learning of oxidation-reduction reactions; offer an opportunity for identification of and establishment of relationship between variables that could be missing in theoretical models (Andriessen, 2006); and use theory to provide a rationale for intervention; interpret findings; and develop a class of theories about the process of leaning (Mishra & Koehler, 2006) . It further helps take care of complexities of classroom teaching and provide researchers with opportunities to study the detailed implementation of interventions with evolving pedagogical goals in rich authentic settings (Mishra & Koehler, 2006). This design-based study will employ both quantitative and qualitative methods (Cohen, Manion, & Morrison, 2007; Creswell, 1994; Wang & Hannafin, 2005) and two or more research approaches such as case study, survey and quasi-experimental at different stages (Andriessen, 2006; Kelly, 2010; Mejia, 2009; Richey & Klein, 2005) to study the process (Richey & Nelson, 1996) of improving chemistry students' conception of oxidation-reduction reactions at the SHS level.

The rationale for adopting design-based research for the study is to focus on constructing and validating an instructional intervention; where the relationships amongst the students' initial alternative conceptions and other difficulties as well as performance will be used to account for the changes that could occur in such relationships over time (Cohen et al., 2007). The developmental nature of the design will be the iteration of the intervention material as the researcher works with students.

In design-based research, van den Akker (2010) explained that the quality of the intervention is usually off-loaded from content and construct validity to practicality (which is the consideration of the intervention as appealing and usable under normal conditions) to effectiveness (which is the extent to which experiences and outcomes with the intervention are consistent with the purpose of the intervention).

Andriessen (2006) emphasized that design-based research is neither a paradigm nor a methodology but a research targeting finding solutions to particular research problem. However, the methodology of design-based research could be described as being less demanding in terms of standards. This less rigid nature of the methodology of design-based research at times is made worse by unforeseen environmental forces of the product or instruction being developed (van den Akker, 1999). As explained by van den Akker (1999), the findings of design-based research cannot be usually generalised using statistical measures to the larger population as the sample is purposively selected. It is always left in the domain of readers of design-based research to infer the findings to their respective situations.

Summary of Reviewed Literature

Conception is simply a general learning experience (Boulton-Lewis, 2004; Entwistle & Peterson, 2004). Students' conceptions of learning can be grouped as quantitative and qualitative conceptions (Chan, 2007). The five different conceptions of learning are increase of knowledge; memorising; the acquisition of facts, procedures; abstraction of meaning; and interpretative process (Boulton-Lewis, 2004; Burnett et al, 2003; Kapucu & Bahcivan, 2014; Richardson, 2011).

The quantitative and qualitative groups of conceptions of learning are contrasting with deep and surface learning which are built upon meaning making and memorisation (Burnett et al., 2003). Students' conceptions are influenced by specific context (Burnett et al., 2003; Entwistle & Peterson, 2004; Richardson, 2011).

There is difference between male and female conception of learning science in the dimensions of memorising and testing, which are traditional conceptions of learning (Kapucu & Bahcivan, 2014). There is a strong relationship between all pre-university students' conception of learning and their academic achievement and there is strong relationship between pre-university students' number of conceptions of learning and their academic achievement (Alamdardoo et al., 2013), there is a relationship amongst student self-concept, conceptions of learning, and strategies to learning; where student self-concept mediates between conceptions of learning and strategies to learning (Burnett et al., 2003).

Students' conceptions are termed as alternative conceptions, which are students' ideas that are not accepted by the scientific community (Guest, 2003; Wenning, 2008; Yip, 1998). At times, alternative conceptions may make sense but are not scientifically accepted (Guest, 2003).

The three classes of alternative conceptions are informal ideas, erroneous ideas, and wrong concepts (Yip, 1998). These are perceived by the senses (Guest, 2003).

Alternative conceptions are caused by commonsense reasoning, which is built on the use of heuristics (Talanquer, 2006). Alternative conceptions can be developed from misunderstanding, miscommunication, miseducation, and misapplication of scientific concepts and ideas (Wenning, 2008).

Students' alternative conceptions are difficult to change (Salame et al., 2011; Wenning, 2008). Constructivist instructions that offer students opportunities to challenge their alternative conceptions can cause conceptual change (Gaitano et al., 2013; Osman & Sukor, 2013; Wenning, 2008).

The use of diagnostic test can help to identify alternative conceptions (Osman & Sukor, 2013). Any teacher instruction that fails to identify and take advantage of alternative conceptions may not cause any conceptual change. Teachers attempt to address students' alternative conceptions lead to development of pedagogical content knowledge (Mdachi, 2012).

The four models of oxidation-reduction reactions are oxygen model, hydrogen model, electron model, and oxidation number model. Combustion, which is addition of oxygen to combustible material is referred to as oxidation. Liebig considered oxidation as loss of hydrogen. Arrhenius explained oxidation as an increase in an ion charge and reduction as a decrease in ion charge of a specie. Oxidation is increased in oxidation number and reduction is decreased in oxidation number. The concept of oxidation-reduction reactions can be applied in both inorganic and organic Chemistry (Osterlund, 2010).

There are two approaches to balancing oxidation-reduction reactions. These are oxidation number method and half reaction method (Romero, 2009). The half reaction method is also referred to as the ion-electron method for reactions occurring in both acidic and basic media (Chang, 2003).

Chemical concepts like any other scientific concepts are associated with conceptual difficulties (Adu-Gyamfi et al., 2012; Ali, 2012; Bond-Robinson, 2005; De Jong et al., 1995; De Jong & Treagust, 2002; Felder, 1993; Hanson, 2010; Zoller, 1990).

Students' failure to appreciate that oxidation and reduction reactions occur simultaneously but not mutually exclusive reactions is a difficulty (Osterlund & Ekborg, 2009). Student difficulty in learning chemical concepts is from the fact that explanations in chemistry requires students to use the multiple means with which chemists reason in relation to chemical process (Bond-Robinson, 2005).

The difficulty of students in chemical concepts is partly due to student inability to correctly write and balance chemical equations (Hanson, 2010). The difficulty in teaching and learning of chemical concepts is as a result of the way topics are sequence in chemistry curriculum materials such as textbooks (Ali, 2012).

Students' perception that oxygen always forms part of oxidation-reduction reactions contribute to their difficulty in learning the concept (Osterlund & Ekborg, 2009). Chemistry teachers have a difficulty in helping students to accept the electron model as the concept for explaining and identifying oxidation-reduction reactions (De Jong et al., 1995). Very few students are able to adopt the concept of electron transfer model in explaining oxidation-reduction reactions (Osterlund & Ekborg, 2009).

In participatory learning methods are not fixed but are selected as when the need arises (Pain et al., 2011). Participants in participatory learning are involved in reflection (Pain et al., 2011).

Since all members in participatory learning are involved in the process of instructional design (Su et al., 2010), it creates a sense of ownership among participants (Andriessen, 2006). Participatory learning ensures two-way communication between target and researchers (Trauth-Nare & Buck, 2011). Participatory learning makes use of task which is the problem and process of the day (Landcare Research, 2002).

A 15-minute reflection could slow down instruction but helps to get to the target (Pain et al., 2011) and reflection helps to put into practice theoretical viewpoint of formative assessment (Trauth-Nare & Buck, 2011). Designers of participatory instructions are to involve end users in designing the instructions (Su et al., 2010).

Learning in today's world must involved students in a learning environment that is collaborative and enhances meaningful learning through the process of critical thinking such as discussion (Chuen et al., 2008). Teachers facilitate and do not dominate in participatory instruction (Pain et al., 2011)

Students create and solve problems as well as evaluate and settle disputes in participatory learning (Shen et al., 2004). In group discussions students learn to agree, disagree and have mutual respect for each and other views (UNESCO, 2001). Participatory learning brings about student satisfaction at the end of instruction (Shen et al., 2004). Students are engaged actively in participatory instruction (McLoughlin & Lee, 2007; Shen et al., 2004).

Sharing of ideas is important in participatory instruction as students experience and understand the subject or topic in different ways (Landcare

Research, 2002; Liu et al., 2013). There is a call for teaching and learning process using participatory instruction (Liu et al., 2013) as it offers students more opportunities (Shen et al., 2004).

Success in participatory instruction is achieved through collaboration of students in groups (Chuen et al., 2008; Liu et al., 2013). Several forms of interactions evolve and inquiry-based learning can be fused into it to better assist students in designing, solving, and evaluating problems in participatory instruction (Shen et al., 2004).

In a constructivist's paradigm, knowledge is constructed by each individual but not transmitted from one person to another (Landcare Research, 2002). Constructivism is a learning theory where students make meaning of material individually and socially (Hein, 1991); as they handle concepts and reflect on their process (Tetzlaff, 2009); and from external reality (Lowenthal & Muth, 2008).

In the eyes of constructivists; students are important subject (Osborne, 1993) and should be actively engaged in the process of making meaning (Jones & Brader-Araje, 2002). The role of the individual student, the importance of making meaning, and the active role of students in the teaching and learning process are important things to consider under constructivism (Jones & Brader-Araje, 2002).

The introduction of constructivism has helped change the focus of knowledge as a product to knowledge, as a process of knowing (Jones & Brader-Araje, 2002) and constructivism is currently the most important learning theory for educational policies, models, and practices (Brown, 2005). Students come out of constructivist lesson feeling accomplished and confident (Cooperstein & Kocevar-Weidinger, 2004).

There are two forms of constructivist learning theories; individual constructivism and social constructivism. This could be described as continuum with individual meaning making at one end and meaning making amongst group of individuals at the other end (Lowenthal & Muth, 2008).

According to Piaget's constructivism, students can make meaning of an abstract concept because humans are rich genetically with the potential to construct the apparatus necessary for abstract thinking through the process of iteration (Taber, 2011). Students make meaning of concepts because whenever they encounter new concepts they use the previous cognitive resources to make sense of the new concepts (Taber, 2011).

Students use cognitive tools (such as insight, information processing, perceptions, and memory) to facilitate meaning making of new materials (Torre et al., 2006). Assimilation of new material is enabled by existing cognitive structures (Hein, 1991).

The social constructivism explains that knowledge is co-constructed and there is collectiveness in some mental functioning such as group problem solving (Ernest, 2010). Student personal concepts are modified through social interactions (Taber, 2011). Internalisation is the most effective result of social learning (Tetzlaff, 2009). Social constructivism assigned importance to the social environment and interpersonal relations in teaching and learning process such as negotiation, collaboration, and discussion (Ernest, 2010).

Vygotsky's zone of proximal development is the point where students could not make meaning of concepts without a support but could make meaning with support from another who is more knowledgeable or experienced in the concept (Ernest, 2010; Kruse, 2009; Taber, 2011). Teachers should know individual student's zone of proximal development and take advantage of it and any teaching targeting the zone of proximal development can bring about further learning (Taber, 2011).

Effective teacher instruction needs to be student-centered as well as teacher-directed. This is because at the zone of proximal development, teacher needs to monitor and direct learning (Taber, 2011). Social interactions in constructivism are an opportunity for students to expand and modify their thinking and share ideas (Tetzlaff, 2009). In social learning environment where students are aided by more experienced hands, there is maximum use of time (Tetzlaff, 2009).

In the classrooms of teachers who value students' ideas and promote the process of critical thinking is the very conducive environment for testing ideas (Jones & Brader-Araje, 2002). Any teaching that targets beyond what is known and understood today facilitates meaningful learning (Taber, 2011). Teachers must be consistent with the ways of presenting new information to students in social leaning environment. This is very necessary in order to avoid conflicting communication to students. Individual student ability to undertake certain activities is good grounds enough to assuming that student has made meaning of the principles underpinning the new activities (Tetzlaff, 2009).

Both social and psychological constructivist learning theories assumed that students actively make meaning in their minds (Richardson, 2003). Social interaction through small group activities and discussions plays key role in students' meaning making as they learn and share knowledge (Cooperstein & Kocevar-Weidinger, 2004). The social and radical forms of constructivism could easily be integrated into today's educational strategies (Jones & Brader-Araje, 2002).

Biological maturation and experience are factors that affect students' level of meaning making and hence, students must be developmentally ready to make meaning of concepts (Kruse, 2009). In all forms of constructivism, students' previous knowledge and experiences are very necessary for further meaning making (Ernest, 2010).

Teachers must identify students' misconceptions and learning errors and deploy diagnostic teaching and cognitive conflict strategies to help students overcome these misconceptions and errors (Ernest, 2010). An effective instruction depends on teachers' decision making relating to teachers' knowledge of the content, subject pedagogy, and the nature of students in the class (Taber, 2011).

All constructivist instructional strategies use group work to facilitate shared knowledge of a concept; provide opportunities for students to determine, challenge, change, or add to previous experience and knowledge; develop students' metawareness; place the student at the centre of the teaching and learning process (Richardson, 2003). In all constructivist learning environment, teachers use individual difference to lay the basis upon which students can make meaning of new knowledge (Tetzlaff, 2009).

Over reliance on didactic teaching and learning strategies was not good enough for all students and over reliance on constructivist strategies such as co-operative and discussion-based activities for meaning making could not be good enough for all students (Osborne, 1993). There is therefore no single, effective teaching strategy for teaching and learning of concepts (Landcare Research, 2002).

Constructivist learning theory does not eliminate teachers entirely from assisting students. The role of teacher is to facilitate by asking questions, making suggestions, and explaining concepts in the teaching and learning process (Tetzlaff, 2009; Wilson, 2010). Teacher facilitation helps to prevent student development of misunderstanding (Brown, 2005; Wilson, 2010).

In constructivist instruction, teachers must conduct 'needs assessment' of the content and put structures (scaffoldings) in place to safe guard the skills and concepts students are expected to acquire at the end of the instruction (Cooperstein & Kocevar-Weidinger, 2004).

Students in general make different versions of meaning of what they are taught by teachers but a reasonable proportion of them make similar meaning of such concepts in line with the intended objectives of lessons (Taber, 2011). Constructivist learning theories explain that teachers teaching abstract concepts which cannot be directly instructed or demonstrated to students must devise means such as the use of models, analogies, and metaphors to assist students create linkages with the new knowledge (Taber, 2011).

Teachers using constructivist learning theories must provide students with opportunities of reflecting on concepts (Cooperstein & Kocevar-Weidinger, 2004; Hein, 1991) as students make meaning from reflection (Ernest, 2010). Students reflect within a reasonable time period (Hein, 1991). Constructivist instruction should provide students with opportunities that create cognitive conflict between students' previous knowledge and experiences and the new information (Jones & Brader-Araje, 2002).

Constructivist instructional strategies such as authentic problems and tasks, discovery learning, group projects and discussion, student choice, and authentic assessment make students active and use students' previous experiences (Lowenthal & Muth, 2008). Notwithstanding an adoption of constructivist learning theories in informing teachers' selection of instructional strategies, teacher-centered instructional strategies cannot be excluded entirely as they all about meaning making (Lowenthal & Muth, 2008).

Teacher view of nature of knowledge influences the selection and use of instructional strategies (Hein, 1991). Teacher deep and strong content knowledge as well as learning to learn and reflection on the strategies are important tool in a constructivist classroom (Hendriks et al., 2010; Richardson; 2003).

The benefits of constructivist instruction include the fact that it corresponds to how students really learn; development of high-order thinking;

integration of emotions, affect, and engagement into discussions of learning and cognition; and it is applicable to out-of-classroom needs (Wilson, 2010).

Teachers need to use instructional strategies that will actively engage students mentally to confront any misconceptions and reflect accurate meaning making (Kruse, 2009). In constructivist instruction, students build on concepts through activities (Cooperstein & Kocevar-Weidinger, 2004). The constructivist learning theories provide teachers at all levels of education with sound theoretical basis for selection of instructional strategies (Taber, 2011).

PCK describes the knowledge of content that enables teachers to develop and use tools for effective teaching and learning (Shulman, 1987). Content knowledge is the actual subject matter to be taught and pedagogical knowledge is the processes and practices of teaching and learning such as student learning, classroom management, lesson plan development and implementation, and student evaluation (Mishra & Koehler, 2006).

Teacher instruction represents PCK when it connects the how, why, and what of the subject matter to students who are to learn that subject matter (Mulhall et al., 2003). PCK is teacher interpretations and transformation of subject-matter knowledge in the context of facilitating student learning. When transformation occurs, subject matter can be used effectively and flexibly in the interactions amongst teachers and students (van Driel et al., 1998). Chemistry teachers can transform nanoscopic explanation by making known to students the importance of objects and materials; pictorially illustrating the macro mechanical system; writing chemical symbols; and using the mathematical relationships (Bond-Robinson, 2005).

Transformation in chemistry could be achieved through making students see things as chemists do (Bond-Robinson, 2005). Transformation of subject matter is the pivot of PCK, which is the intersection of subject matter and pedagogy and not just a simple consideration of both (Mishra & Koehler, 2006). Teachers develop PCK through the processes of teaching and learning (van Driel et al., 1998; Wilson & Peterson, 2006).

Teacher development of PCK is embedded in the classroom and beginning teachers and experience teachers have little or no PCK in specific topics that they have never taught (Mulhall et al., 2003; van Driel et al., 1998). PCK is a special aspect of knowledge that teachers possess with respect to teaching specific subject matter to particular group of students (Mulhall et al., 2003).

Effective science teaching and learning; the complicated nature of teacher thinking; and ways of enhancing understanding of teaching experiences of teachers can be used to develop topic specific PCK (Mulhall et al., 2003).

The two interrelated domains of the PCK are teacher knowledge of presentation of subject matter and teacher meaning making of student learning difficulties and conceptions (van Driel et al., 1998).

The five components of PCK are epistemology, cognition, teaching resources and techniques, affect, and interaction (Godino et al., 2008). These agreed on the two domains of Shulman's PCK (van Driel et al., 1998).

Teachers with an in depth pedagogical knowledge understands how students construct knowledge (Mishra & Koehler, 2006). Teachers gain craft knowledge through previous education, personal background, teaching context, and teaching experience (Bond-Robinson, 2005). PCK helps teachers to adopt instructional strategies that enable them use appropriate conceptual representations to address students' difficulties in concepts (Mishra & Koehler (2006).

Most of the forms of representations such as analogies, illustrations, examples, explanations, and demonstrations are ways of representing and formulating subject matter to make it understandable to students (Mishra & Koehler, 2006; Shulman, 1986). The teachers with more representations better recognise learning difficulties. Such teachers effectively deploy their PCK. With PCK teachers make meaning of students' learning difficulties and preconceptions (van Driel et al., 1998).

Learning is self-regulated with promising avenues for students to discover and to interpret findings from such discoveries (Hendriks et al., 2010). Learning has three attributes. Learning is a process of active construction, a social phenomenon (and an individual experience), and learner differences are resources, not obstacles (Wilson & Peterson, 2006). Active involvement of students in learning in groups contributes to meaning making (Felder, 1993; Peterson, 2006).

Constructivists believe that students actively make meaning of concept does not mean that the role of teachers is insignificant. Teachers provide support such as questions (Kruse, 2009). Active learning environment is student-, knowledge-, and assessment-centred (Mundry, 2005).

Behaviour change could be equated to knowing what to do, creating enabling environment, and being motivated. This can be achieved through student-centred strategies. Behaviour change is not only an individual learning active but a social process (Landcare Research, 2002).

Learning is a continuum (from non-reflective learning to reflective learning); with a lot of points of interest on this continuum (Herod, 2012). Developmental cognitivists' view of students learning from concrete operational to formal operation with respective to their year should be seen as a continuum (Kruse, 2009). And teaching and learning strategies must be in agreement with the continuum (Herod, 2012).

Student learning style can be classified into sensing and intuition. The sensors are at the disadvantage in learning scientific concepts especially in chemistry and physics. Teachers then need to adopt systematic fraction of additional instructional strategies in teaching (Felder, 1993). When students are exposed to conceptual problems and given the opportunity to solve the problem on their own, and helped to identify and understand the mistakes made as they attempt to solve problem, there is deeper understanding and retention (Felder, 1993).

Social learning theories share the view that knowledge is constructed when students practice what they learn. That is knowledge construction cannot be separated from practice (Wilson & Peterson, 2006). Meaning making of concepts is dependent upon the interactions among individuals in their communities (such as the classroom) and their participation in activities (Wilson & Peterson, 2006). To support students to make meaning of concepts through peer or greater social interactions, teachers must choose instructional strategies that will enable students to collaborate (Kruse, 2009).

Wilson and Peterson (2006) explained that teachers cannot assume only one role in presenting instructional materials to students. Teachers should therefore select their teaching strategies from diversity of learning theories (Wilson & Peterson, 2006). This is because students' learning needs more than one learning theory (Bednar et al., 1995; Landcare Research, 2002; Osborne, 1993; Wilson & Peterson, 2006).

Though the use of varied instructional strategies with roots from behaviouralists and constructivists perspectives is said to be probable but Wilson and Peterson (2006) pointed out it should not be 'anything goes'. Teachers should select instructional strategies base on content, objectives, and student characteristics (Bednar et al., 1995; Cooperstein & Kocevar-Weidinger, 2004; Wilson & Peterson, 2006). In an effective instruction, instructional strategies which are behavioural oriented should be used alongside instructional strategies from the realms of cognitive theories (Kruse, 2009).

The conduct of Design-based research involves design, development, and evaluation of an intervention for teaching a concept (Keppell, Au, Ma, & Chan, 2005; Richey & Klein, 2005; Richey & Nelson, 1996). There are a number of names for design-based research but the basic principles and techniques are the same to all (Wang & Hannafin, 2005).

Design-based research is a systematic but flexible methodology used to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in a natural settings, which result in contextually-sensitive design principles and theories (Wang & Hannafin, 2005). This is to say that design-based research is more appropriate when the problem under study is open and 'wicked' with initial statement of the problem uncertain (Kelly, 2010; van den Akker, 1999).

Design-based research is simply as intervention, iterative, process, utility, and theory oriented (Anto, 2013) and it is cyclical in nature (Andriessen, 2006; Ottevanger, 2001; Plomp, 2010; van den Akker, 1999). Each stage of a design-based research provides the researchers and the practitioners with feedback (Reeves, 2006).

To some researchers there are three stages of design-based research; preliminary research phase, prototyping phase, and assessment phase (Plomp, 2010) and other four stages of design-based research; preliminary, prototyping, assessment, and systematic reflection and documentation stage (Nieveen, McKenney, & van den Akker, 2006).

Design-based research is appropriate in most research situations such as in educational research where single study usually fails to provide the research community with a solution to an identified complex problem (Mckenney & Reeves, 2012; Walker, 2006); when the PCK of the teachers involved is poor;

when a solution to an identified educational problem will result in learning to the researchers and practitioners; and where the outcome of the research work could minimise significantly the malfunction in the educational system (Kelly, 2010).

Design-based research helps to create a linkage amongst research and practice (Romme, 2003); make practical and scientific contributions to education (van den Akker, 2011); offer researchers no constraints of the basic research/applied research dichotomy (Keppell et al., 2005); and enhance the professional development of the pre-service teachers (Andriessen, 2006; Plomp, 2010; Romme, 2003) .

The rationale for design-based research is to focus on constructing and validating an instructional intervention; establish relationships amongst the students' initial alternative conceptions and other difficulties (Cohen et al., 2007). The quality of the intervention is usually off-loaded from content and constructs validity to practicality (van den Akker, 2011). Design-based research is neither a paradigm nor a methodology but a research targeting finding solutions to particular research problem (Andriessen, 2006).

CHAPTER THREE

RESEARCH METHODS

The methods and procedures used in data collection are presented and discussed in the chapter. The methodology is built on design-based research approach. The design-based research approach adopted for the study is composed of preliminary stage, design and development stage, prototype stage, and systematic reflection and documentation stage. The concept of population, sample and sampling procedures, research instruments, data collection procedures, and data analysis plan are respectively discussed under the four stages.

Research Design

The research approach for the study was a design-based research. There were four stages of this design-based research that adapted qualitative and quantitative methods. The four stages were preliminary stage (which was the reviewing of related literature on teaching approaches and students' difficulties in learning chemical concepts); design and development stage (which was the development of initial design guidelines); prototype stage (which was the development of intervention and iterative cycles of the design); and systematic reflection and documentation stage (which was the reflection and analysis to specify the design principles for the intervention for teaching and learning of oxidation-reduction reactions). Figure 2 represents the diagrammatic representation of the design-based arrangement for the study.

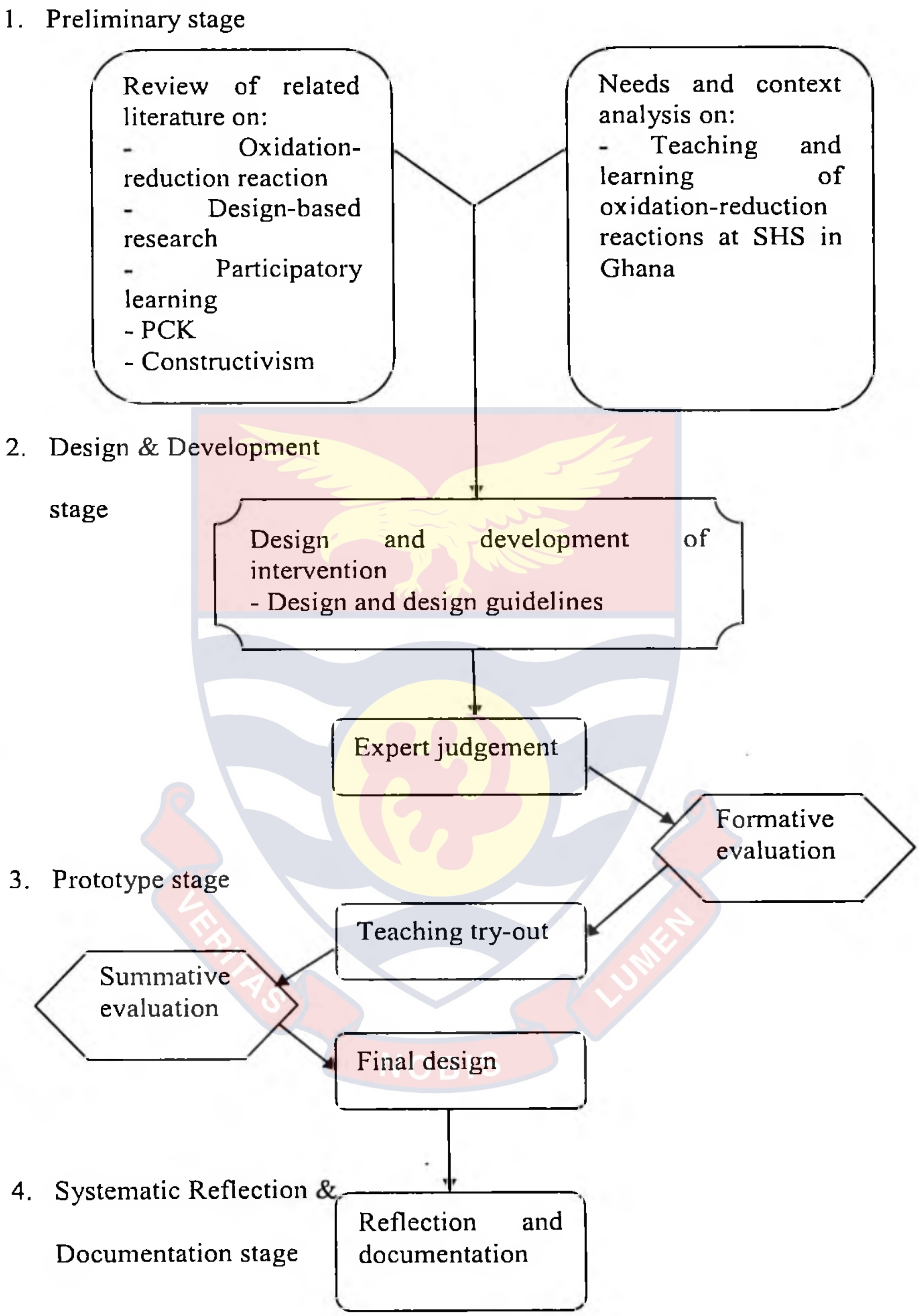

Figure 2. Developmental stages of the design-based research.

Preliminary stage

From Figure 2, at the preliminary stage of the study, a number of activities were conducted ahead of the design and development of the intervention. The related literature on the teaching and learning of oxidation-reduction reactions was reviewed at the beginning of the preliminary activities to establish the conceptual framework of the study. To be able to establish the views of chemistry teachers on the teaching of oxidation-reduction reactions through interviews, literature on teaching was reviewed. The study further reviewed materials in the area of conceptual difficulties in chemical concepts. Other areas of teaching approaches and learning theories in the literature were looked into as part of the review process in developing the conceptual framework of the study.

There was an investigation into issues associated with how effective the teaching and learning of oxidation-reduction reactions was in the Ghanaian SHS. Chemistry teachers' teaching practices and best practices as well as alternative conceptions and other conceptual difficulties of students with respect to learning oxidation-reduction reactions were explored. Thus, the review of literature related to oxidation-reduction reactions and learning theories; the study of teachers' views on; and students' alternative conceptions and other conceptual difficulties in oxidation-reduction reactions served as the preliminary stage of the design-based research.

Design and development stage

The second stage was the design and development of the intervention (Figure 2). This was based on results obtained from the needs and context analysis as well as the reviewed of literature. The intervention, which is Participatory Teaching and Learning Approach (PTLA), consisted of instructional sequence. The PTLA was based upon existing instructional methods suitable to the Ghanaian curriculum. The intervention was given to three experts for validation. Thus, the three experts respectively in the areas of design-based research, instruction, and chemistry content assessed and critiqued the preliminary PTLA. The views and suggestions from the experts were used to improve the quality of the PTLA.

Prototype stage

The prototype stage was the third stage of the study. The prototype stage was the teaching try-out stage using PTLA with second year SHS chemistry students. The class consisted of high and low achieving students; fast and slow learning students; and male and female students. The teaching try-out lasted six weeks. During this period, the researcher instructed students on oxidation-reduction reactions in eight lessons using the PTLA. There was a general discussion held after each lesson between the researcher and the students. Particularly, the discussion was pivoted on the stages of the instructional sequence and the participatory nature of the PTLA. The purpose of the general discussion was to help ascertain the views of students on the strength and weakness of the use of the PTLA in teaching oxidation-reduction reactions. The feedback from students on the use of the PTLA was noted and used to improve the quality of it. In general, the try-out concept was necessary for the study as Andriessen (2006) explained that the validity of any intervention developed as a result of design-based research is dependent upon the try-outs of such design.

In the teaching try-out, the study adopted pretest-posttest single group quasi-experimental design (Cohen et al., 2007) to ascertain the conceptual development of students on oxidation-reduction reactions after the used of the PTLA. Chemistry students involved in this part of the study were selected randomly into only one group and hence the adoption of pretest-posttest single group quasi-experimental design. That is there was interaction with one group of students from the school before, during, and after instruction.

The pretest and posttest items were the same but of different arrangement. The test items were multiple choice test and students had to explain the basis for selection of any of the options as the best or correct answer to any of the items. The purpose of the pretest-posttest quasi-experimental activities during the teaching try-out was to obtain information that helped to investigate how students' alternative conceptions minimised as their conceptual understanding of oxidation-reduction reactions improved (in the light of the new teaching approach employed for the study). Thus, the gains in terms of students' scores and explanations given as well as students' interest before and after instruction were looked at.

Systematic reflection and documentation stage

The final stage of the design as seen from Figure 2 was the systematic reflection and documentation stage. The purpose was to go into retrospection of the design, development, and try-outs of the PTLA as the possible alternative approach for improving students' conceptual understanding of oxidation-reduction reactions at the high school level. The area of improvement sought here was the theory behind oxidation-reduction reactions. The theory was built upon the four models of oxidation-reduction reactions. That is how students conceptualised oxidation-reduction processes, oxidising and reducing agents, oxidised and reduced substances, half reactions, balancing oxidation-reduction equations, and everyday occurrences of oxidation-reduction reactions with respect to the oxygen, hydrogen, electron transfer, and oxidation number models.

In the study, the areas of reflection and documentation included the literature review relating to the study, the outcome of the needs and context analysis, and (formative) evaluation of valid, practical, and effective guidelines for the design and development of the PTLA. Another area of reflection was the role of the researcher. The researcher had an overlapping role of facilitator (in presentation of the lessons in the teaching try-outs) and researcher (during the various sessions of the design of PTLA and data collection). The methods of data collection were reflected upon to consider the validity and the analysis of the data collected.

Population

The study was carried out in SHS in the Ashanti Region of Ghana. There were 30 Metropolitan, Municipal, and District Assemblies (MMDAs) in Ashanti Region. The population for the study was from schools in three out of the 30 MMDAs. In the three MMDAs, there were 14 public and one private SHS. From the 15 schools, science teachers and students (who offered Biology, Chemistry, Physics, and E-mathematics, referred to as elective science students in Ghana) were involved in the study. The target population for the study comprised all science teachers teaching chemistry and all SHS 3 and 2 chemistry students for the 2013/2014 and 2015/2016 academic year respectively from the schools in three district assemblies of Ashanti Region, Ghana.

Sampling Procedure

The 30 MMDAs were stratified into one Metropolitan assembly, seven Municipal assemblies, and 22 District assemblies. Three MMDAs were simple randomly selected (with one from among the Municipal assemblies and two from among the District assemblies). The Metropolitan assembly was excluded because it was a very large study area with large number of public and private schools. Also, schools from the Municipal and District assemblies were selected as the study areas because the characteristics of the schools were similar to those in the Metropolitan assembly.

The 15 schools from the three MMDAs were stratified into elective science and non-elective science schools. The elective science schools were seven in number and the non-elective science schools were eight in number (including the private school). Three schools were simple randomly selected from the seven elective science schools from the three MMDAs for the study.

There were 10 teachers from the three schools with bachelor degrees in chemistry. Of the 10 teachers, 40.0% graduated with Bachelor of Science (chemistry) and 60.0% graduated with Bachelor of Education (chemistry). All the teachers could be described as experienced teachers as they have been teaching high school chemistry for a minimum of 7 years and a maximum of 12 years. The 10 teachers were stratified into teachers currently teaching chemistry and had taught oxidation-reduction reactions in last 5 years and those who had not taught chemistry in the last 5 years. This is because in some of the schools some chemistry teachers were not teaching elective chemistry but Integrated Science. In all the three schools, two teachers were identified as the teachers currently teaching chemistry and hence, participated in the needs and context analysis stage of the study. A total of six teachers were available and shared their views on the teaching of high school oxidation-reduction reactions.

The accessible population of SHS 2 students from one of the three schools was 122 and that of the SHS 3 students from three schools was 213. The population of students comprised high and low achieving; fast and slow learning; and male and female students. Further at the needs and context analysis stage of the study, all the chemistry students in SHS 3 (for 2013/2014 academic year) from the three randomly selected schools (A, B, and C) in the three districts responded to the diagnostic test assessing students' alternative conception and other conceptual difficulties on oxidation-reduction reactions. The schools could be described as well-endowed (A); endowed (B); and less-endowed (C). The total number of SHS 3 students was 213 consisting of 83, 69, and 61 students respectively from Schools A, B, and C. Involving all the SHS 3 students became necessary as only three schools were involved at this stage of the study.

The SHS 2 students for the 2015/2016 were involved in the prototype stage study. Of the three schools that participated in the needs and context analysis stage study, one school was simple randomly selected and participated in the teaching try-out of PTLA. The total number of students in the school was 122. The 122 students were stratified into high and low achieving students based on class performance records and the advice of the class chemistry teacher. From the high achieving students, five students were simple randomly selected into five groups for the teaching try-out and from the low achieving students, 10 students were simple randomly selected into the five groups. The simple random sampling procedure helped to ensure that the male and female students had equal chances of being selected. In all, there were 15 students consisting of nine male and six female students. The technique of random sampling and the lesser number of students was important as the researcher developed the PTLA with the students and that the number offered the researcher and students maximum interactions.

Data Collection Instruments

According to Andriessen (2006), in design-based research a number of research instruments such as interviews, participatory observations, and document analyses could be used to collect data for the study. The research instruments for collecting data for the current study were test and interviews.

Test

Two test-types were used to collect data for the study. These were diagnostic test and achievement test. The achievement test comprised pretest and posttest. From Andriessen (2006), the diagnostic testing stage of design-based research approach provided an opportunity for assessing whether the practice problem was in line with the application domain for which the PTLA was to be designed. The diagnostic tests were used at the needs and context analysis and prototype stages of the study. At the prototype stage, the pretest and posttest were used to establish any improvement in students' conceptual understanding and hence, performance on oxidation-reduction reactions.

Items in the diagnostic test, pretest, and posttest were constructed by the researcher through the following means: First, the SHS chemistry curriculum (MOE, 2010; 2012) was studied carefully to identify the various areas of oxidation-reduction reactions as outlined in the curriculum. The study of the chemistry curriculum further helped to appreciate the nature of evaluation exercises under oxidation-reduction reactions. After the study of the curriculum, some test items were constructed.

Teacher-made assignments, class exercises, and class tests on oxidation-reduction reactions for high school students from three of the elective science schools outside the study zone were also studied. This helped to identify test items used by the teachers and the profile dimension at which teacher-made test items were assessing. Of the teacher-made assignments, class exercises, and class tests, items at application of knowledge level of profile dimension were selected and reworded.

Literature on chemistry education in the area of oxidation-reduction reactions was then studied. From the review, some items were also collected from the literature on oxidation-reduction reactions (Barke, 2012; Chang, 2003; Osterlund & Ekborg, 2009). The test items collected from literature were reworded to suit the current study.

The diagnostic test consisted of 30 multiple choice items. Under each item, students were expected to provide reasons for the respective choice of response. The areas of the diagnostic test were oxidation-reduction processes, oxidising-reducing agents, half reactions, and examples of everyday experience of oxidation-reduction reactions (Appendix A). The diagnostic test structured in this form provided the study with quantitative data from the scores and qualitative data from the explanations written for each response provided. This helped to investigate the types of students' alternative conceptions and other difficulties on oxidation-reduction reactions ahead of instruction.

There were 20 pretest items in the areas of identification of oxidation-reduction reactions, reducing-oxidising agents, and oxidation half and reduction half reactions. Each item required students to select the correct or best option amongst three or four given options. Students were required to give reason to justify the option selected (Appendix B). Each item scored 2 marks; 1 mark for the selection of correct option and other 1 mark, for correct explanation given for the selection of the correct option. A mark-value of zero score was given for failure of students to provide correct response and correct explanation to any test item. The items in the posttest were similar to those in the pretest. However, the arrangement of the items was different (Appendix C). This helped to ensure that the item difficulty level in the posttest was similar to that of the pretest.

Validity and reliability of test instruments: To ensure the content validity of the test items, the items were constructed in such a way that the items covered identification of oxidation and reduction processes, half-reactions (in the case of pretest and posttest), and everyday application of oxidation-reduction reactions (in the case of diagnostic test). These areas were in line with the chemistry curriculum (MOE, 2012). The test items were further compared to the standardised test items in the area of oxidation-reduction reactions set by WAEC. This further ensured the content validity of the test instrument.

The content of the test items were further validated by three seasoned WAEC Assistant Examiners teaching chemistry at the senior high school level and two experts in instructional design and chemistry education from the University of Cape Coast. The five individuals gave professional judgments about the relevance and sampling of the content of oxidation-reduction reactions to the intended purposes of the test instruments. Upon the critique and suggestions of the WAEC Assistant Examiners and the experts, five and six of the test items respectively were dropped leaving 25 items in the diagnostic test and 14 in the pretest and posttest. The items dropped were identified as too challenging and could be ambiguous to students at the SHS level.

The items in the diagnostic test, pretest, and posttest instruments were pilot-tested with 10 students selected by simple random sampling techniques respectively from a class of 55 SHS 3 students and 70 SHS 2 students from a high school in the Cape Coast Metropolis. The SHS 3 and 2 students were involved in the pilot test as the tests were responded to by students of identical characteristics from the main study zone. After the pilot test, the items in the test instruments were subjected to item analysis. The purpose of the item analysis was to establish the item difficulty and discrimination indices. This enhanced the internal consistency of the test instruments. During the test item analysis, all items that were found to be too difficult or too easy were deleted.

KR-20 coefficient of reliability was calculated for the test instruments. The KR-20 was used to calculate the reliability coefficient because there were unequal item difficult indices for items on the test instruments (Brennan & Lee, 2006). Also, the KR-20 was used because the items in the test instruments were scored 1 mark each for correct option selected and explanation given and 0 mark for wrong response. The KR-20 values assisted to determine whether the diagnostic test, pretest, and posttest instruments were reliable. After deletion of seven items from the diagnostic test, the KR-20 coefficient of reliability for the 18-diagnostic test item was calculated as 0.87. And after the deletion of four items from pretest and posttest, KR-20 coefficient of reliability was calculated as 0.84. These values of KR-20 showed that the test instruments were reliable.

Interview

The interview schedules of the study comprised teacher interviews, student interviews, and prototype stage student interviews. The interview items used in the three interview schedules were constructed by the researcher. The items were constructed based on the researcher's personal teaching experiences and literature on constructivism, participatory learning, and teaching and learning strategies. The three interview schedules were semi-structured, where teachers and students responded to the same respective basic items during the interviews.

With respect to the teacher interview schedule, there were seven basic items. The items were looking for teaching experiences, strategies to teaching, challenges associated with teaching, and any support systems to enhance teaching of oxidation-reduction reactions (Appendix D).

With respect to student interview schedule, there were four items similar in construction (Appendix E). The questions basically were looking for student justification of responses given to any of the test items on the diagnostic test. The prototype stage interview schedule consisted of six items. The items were looking for the views of students on the success or failure of the lessons with, participatory nature of, and teacher's role in lessons with PTLA (Appendix F).

Validity and reliability of interview instrument: To ensure content validity of the questions on the interview schedules, they were shown to two experts in instructional design and chemistry education. The suggestions from the experts were used to improve the quality of the items on the interview schedules. Internal validity of teacher interviews was ensured through credibility where the researcher offered teachers opportunity to add further information to what they had stated earlier on.

For the external validity of the interviews, there will be transferability of data. That is sufficient data on teacher interviews on teaching of oxidation-reduction reactions and student interview on conceptual understanding on oxidation-reduction reactions will be provided in the current study for readers and users.

For the reliability in the interviews, the same basic items in the same sequence were used in the teacher interview schedules (Appendix D) and in the student interview schedules (Appendices E and F). In addition, interviews schedules with teachers and students were dialogue in nature. The teachers and students were given sufficient time to organise their thought before responding to any item.

Data Collection Procedures

A letter from the Head, Department of Science Education, University of Cape Coast, was submitted to the authorities of the schools where the study was conducted. The purpose of the letter was to enable the researcher ask for permission and consent of the school authorities for the conduction of the study. This in one breath helped prevented any unforeseen interruptions that the study could have encountered from the authorities and the science teachers. The concerned authorities were further briefed on the purpose and the benefits of the study to the schools and chemistry education in the country as a whole. A briefing session on the purpose and various stages of the study was organised for the students. This helped the students to understand and appreciate what was expected of them during the study. The administration of the research instruments which were the teachers' interviews, students' interviews, prototype stage interviews, and tests on oxidation-reduction reactions was performed by the researcher. The students' interviews and administration of test instruments were carried out in the presence of school science teachers. The purpose was partly to ensure that teachers felt they were part of the study and that students felt comfortable responding to the test items seeing their regular science teachers around.

During the first week of the context and needs analysis study, chemistry teachers from the three schools were interviewed by the researcher using teacher interview schedule (Appendix D) on the difficulties of teaching oxidation-reduction reactions at the SHS level. Where there was the need for follow up interviews, it was conducted to ensure the validity of the views of teachers. Teachers' views on the teaching of oxidation-reduction reactions were analysed and the outcomes used to identify and define the nature of the difficulty of teaching oxidation-reduction reactions. The findings from teacher interviews were further factored into the design and development of PTLA for teaching oxidation-reduction reactions.

In the second week of the context and needs analysis study, the researcher administered the two-tier diagnostic test to the SHS 3 students. The researcher moved from School A to B and C on three respective days. In each school, the test was administered and collected on the same day of the visit. The diagnostic test was scored immediately after the test administration to facilitate the calculation of the mean scores of students. With the help of the mean scores, students from each school were stratified into the below average, average, and above average groups for the group interviews. Thereafter the groupings, the group interviews were conducted within the same week. Students' scores and explanations under the diagnostic test were analysed to further help in recognition and definition of the problem with learning of oxidation-reduction reactions.

Research Question 3 sought to establish techniques and strategies that can be used to improve students' conceptual understanding of oxidation-reduction reactions based on the research literature. In order to establish the strategy, literature on teaching and learning relating to oxidation-reduction reactions were reviewed. The intervention, participatory teaching and learning approach (PTLA) was such an instructional sequence. The sequence offered students more opportunities to learn than just taking in knowledge from the teacher. The instructional sequence followed the pattern illustrated in Figure 3.

The instructional sequence was designed for the purposes of identifying and addressing students' alternative conceptions in learning oxidation-reduction reactions; presenting the concept of oxidation-reduction reactions in a way that offered students maximum interactions in learning chemistry; and improving students' conceptual understanding of oxidation-reduction reactions. The use of the sequence became necessary as there was no single instructional strategy appropriate for the PTLA, which was a complex process (Landcare Research, 2002). The PTLA followed the pattern: Insight→Interaction→Task→Forum.

Stage 1 (Insight): Exploration of students' conceptions

Insight was the starting stage of the PTLA. It was designed to deduce students' conceptions in the various aspects of oxidation-reduction reactions. This was because students came into the classroom with previous knowledge and experiences on oxidation-reduction reactions not in agreement to that accepted by the scientific community (Sjoberg, 2007). Students were given questions on the various aspects of oxidation-reduction reactions to respond to in written form. Students were expected to respond to the given questions using their previous experiences and knowledge. The deduction of students' conceptions was important to the study as it was reported that teachers must first identify students' alternative conceptions to a concept to be able to deploy the appropriate strategy to help students overcome such alternative conceptions (Ernest, 2010; Kruse, 2009).

Stage 1: Insight

Exploration of Students' Conceptions

- Oxidation-reduction processes
- Half reactions
- Balancing redox reactions
- Everyday application of redox reactions

⇓

Stage 2: Interaction

Discussions of Students' Conceptions

- Analyse to accept or reject alternative conceptions
- Give other alternative conceptions

⇓

Stage 3: Task

Finding Solution to the Problem of the Day

- Oxidation-reduction processes
- Half reactions
- Balancing redox reactions
- Everyday application of redox reactions

⇓

Stage 4: Forum

Presentation of Solution to Task

- Consideration of views of students
- Evaluation of students' solutions

Figure 3: General instructional sequence for oxidation-reduction reaction.

The aspects considered were oxidation-reduction processes, half reactions, balancing of redox reactions, and everyday application of oxidation-reduction reactions. This means there was more than one lesson where the Insight strategy was used. In one lesson, students' conception of oxidation-reduction processes was deduced and in another, students' conceptions of half reactions; follow by students' conceptions of balancing oxidation-reduction reactions; and students' conceptions of everyday application of oxidation-reduction reactions was deduced. Students' conceptions were categorised as "correct conception" and "alternative conceptions" in each lesson for the Interaction stage.

Stage 2 (Interaction): Discussion of students' conceptions

Interaction was the stage where students shared ideas on students' conceptions categorised as correct and alternative conceptions to accept or not to accept. The Interaction was a key stage in the PTLA because Wilson (2010) reported that the process where students make meaning of material is an active process achieved through experiences and interactions with the world. At the Interaction stage, there were student-student interactions on the correct and alternative conceptions followed by student-teacher interactions. These two forms of interactions provided students with opportunities to develop correct conceptual understanding on oxidation-reduction reactions.

The Interaction strategy was used partly because knowledge is supposed to be constructed by the individual student but not transmitted from one person to another (Landcare Research, 2002). Such knowledge construction could be achieved individually or socially (Hein, 1991; Lowenthal & Muth, 2008; Sjoberg, 2007). Students' meaning making through social interactions is being placed ahead of any constructivist instruction (Brown, 2005); hence the adoption of student-student and student-teacher interactions.

The Interaction stage was also appropriate for the PTLA as students incorporated their experiences and views to construct knowledge (Tetzlaff, 2009) and that students made meaning of oxidation-reduction reactions through their collaboration, negotiation, and involvement in authentic communities of practices (Ernest, 2010; Wilson, 2010).

Student-teacher interactions were used because the PTLA was built in constructivist instructions which were student-centred and teacher-facilitated. The student-teacher interaction was important to the Interaction stage as research has revealed that at the zone of proximal development, students could make meaning of oxidation-reduction reactions with support from the teacher who was knowledgeable and experienced in the concept (Ernest, 2010; Kruse, 2009; Taber, 2011). At the zone of proximal development in learning oxidation-reduction reactions, students needed to be monitored and directed (Taber, 2011). The involvement of the teacher who was knowledgeable and experienced in oxidation-reduction reactions helped students maximised time in making meaning of the concept (Tetzlaff, 2009). However, teacher guidance in learning oxidation-reduction reactions was minimal at this stage (Taber, 2011).

A single lesson comprised the Insight and the Interaction strategies. The lessons under the Insight and Interaction lasted 90 minutes each. Within the 90 minutes, students first worked individually, followed by work in groups, and finally had a whole class interaction with the teacher. The individual work offered the teacher the opportunity to deduce individual student's conception of oxidation-reduction reactions; the group work offered the teacher the opportunity to appreciate which student conceptions were accepted or not accepted by students; and the interactions with the teacher helped the teacher to correct students' conceptual understanding of oxidation-reduction reactions. The details of the lessons under the Insight and Interaction stages are presented in Lessons 1, 3, 5, and 7 (Appendices G, H, I, and J).

Stage 3 (Task): Finding solution to the problem of the day

The Task was the third stage of the PTLA. The teacher first guided students to revise previous lessons on the oxidation-reduction reactions. Students then solved the task (the problem of the day) which was not only an attribute of constructivist instruction (Wilson, 2010) but a strategy used in participatory learning (Landcare Research, 2002). The problem of the day was given on a worksheet and students responded to the problem in groups. The group interactions as an attempt to find solution to the problem (UNESCO, 2001) provided students with an opportunity to share ideas in solving the problem of the day. The group interactions also provided students collectiveness in problem solving (Ernest, 2010).

Students found the solution to any given problem as a process. That is students teamed up in the groups in solving the given problem (Landcare Research, 2002). Time was an important factor in the process as a long period of time was needed by the students to make meaning of the concept of oxidation-reduction reactions (Hein, 1991; Taber, 2011; Tetzlaff, 2009). Hence, students were given 30 minutes to look for the solution to any given problem of the day.

Students were provided with instructions, to ensure orderliness in the groups, as they interacted to solve the problem of the day. That is the instruction spelt out rules for working in groups such as: 1) respect each other view; 2) talk only when your turn to is; 3) guide against unnecessary arguments; and 4) write only points agreed upon by group members. This ensured that none of the group members dominated or imposed their respective views on the other students in the group but shared ideas, agreed or disagreed to come out with the solution to the problem of the day.

Stage 4 (Forum): Presentation of solution to task

The Forum was the stage of the PTLA during which students presented solutions and judged the most appropriate solution to a given task. One student from each group presented the solution to the day's problem on behalf of the group and explained the solution to the class. Students were allowed to raise issues about the solution presented. The Forum therefore ensured a two-way communication system where students shared ideas as a class and with the teacher (Trauth-Nare & Buck, 2011). This offered students opportunity to expand and modify their thinking and ideas (Cooperstein & Kocevar-Weidinger, 2004; Tetzlaff, 2009) on oxidation-reduction reactions.

In a two-way communication, students were allowed to challenge any solution presented by other group members on any given task (Richardson, 2003) on oxidation-reduction reactions. This in some instances generated disputes among students. The disputes were not directly settled by the teacher. Students settled any disputes as they attempted to argue on the correctness of solutions presented on any given task (Shen et al., 2004) and in an attempt learnt from each and another.

Students having finished settling the disputes and judging the most appropriate solution to the problem, the teacher stressed on the correctness of the concepts appropriate for solving the day's problem. This contributed to students' conceptual development on the concept of oxidation-reduction reactions.

Lessons on the Task and Forum were a unit. That is there were individual lessons after those on the Insight and Interaction stages which comprised the Task and the Forum stages. Lessons under the Task and the Forum took 90 minutes each. The details of the lessons under the Task and Forum stages are presented in Lessons 2, 4, 6, and 8 (Appendices G, H, I, and J).

Methods of evaluation of PTLA in teaching oxidation-reduction reactions

The prototype stage of the study was the stage where the PTLA for the teaching and learning of oxidation-reduction was used in teaching try-out. This stage of the study was guided by two of the research questions. In this stage of the study, the procedures for evaluating the PTLA were outlined, which in effect helped answered the two research questions.

Research Question 4 sought to find out the effectiveness of the new teaching approach (PTLA) on students' conceptual development on oxidation-reduction reactions. The research question was answered from the data collected with tests and interviews. In the first part of the Research Question 4, students responded to pretest at the beginning of the study and the posttest at the end of the study. The quality of students' performance was established by comparing students' test scores to that of the explanations given. The scores of the individual students in the pretest and the posttest were compared to establish any improvement in the student's performance in the second part of the Research Question 4. In the third part of the Research Question 4, students written explanations in solving the four problems of the day were examined to find out any improvement in the students' conceptual understanding of oxidation-reduction reactions. Finally, students' explanations given to any of the test items in the pretest and the posttest were compared to further establish students' conceptual understanding of oxidation-reduction reactions.

Research Question 5 helped to find out the views of students about the PTLA. Students' views about the PTLA (with respect to the strategies used, participatory nature of the instruction, and role of teacher) were established through interviews between the teacher and students after each of the eight lessons.

Data Processing and Analysis

The data collected with the research instruments was analysed using both descriptive and inferential statistics and themes. Research Question 1 was answered using percentages, means, and standard deviations. In the analysis of the diagnostic test, which was a two-tier multiple choice test, percentages of students' correct responses and foils to each oxidation-reduction reaction test item were presented and discussed. In the discussion of students' scores, the description was broadened to cover the percentage-scores of the alternative conceptions to the test items. The explanations given by students for each of the options in the diagnostic test were categorised and analysed under alternative conceptions and other conceptual difficulties using open coding and constant comparison. The themes so constructed were based on the interpretations the researcher gave to students' explanations to each test item.

Research Questions 2 was answered by transcribing the views of the teachers respectively on the teaching and the difficulties teachers encountered teaching oxidation-reduction reactions at the SHS level. The researcher then made meaning out of teachers' explanations given with respect to how the concept of oxidation-reduction reactions was presented to students. From the meanings so constructed from teachers' explanations, themes were deduced, analysed, and discussed thereafter.

Research Question 3 was answered using terms deduced from the literature on constructivism, PCK, participatory learning, and instructional strategies. The terms were then referred to as stages incorporated into the PTLA as instructional strategy. The stages were Insight→Interaction→Task→Forum.

Research Question 4 was answered using percentages, means, standard deviations, and themes. In the first part of the Research Question 4, the percentages were used to establish students who scored each item on the pretest and the posttest. The means and the standard deviations were used to established students' performance on the pretest and posttest. The scores of individual students in the pretest and the posttest were compared to establish any improvement in the student's performance in the second part of Research Question 4. The related samples t-test was used to test for any statistical significance difference between students' mean scores in the pretest and posttest. The related samples t-test was used because when the normality of the distribution of the scores was tested using the Kolmogorov-Smirnov test, the distribution of scores in the pretest and posttest was normal. This is because it was established that the pretest scores were sufficiently normally distributed ($p = 0.906$, Kolmogorov-Smirnov, $Z = 0.566$) as were the posttest scores ($p = 0.575$, Kolmogorov-Smirnov, $Z = 0.781$). The Pearson correlation coefficient was used to establish any relationship existed between students' posttest scores and that of their pretest scores.

In the third part of the Research Question 4, students written explanations in solving the four problems of the day in Lessons 2, 4, 6, and 8 were constantly compared under identification of oxidation-reduction reactions, half reactions, balancing of oxidation-reduction reactions, and everyday application of oxidation-reduction reactions to find out any improvement in the students' conceptual development on the concept. In the last part of Research Question 4, students' explanations in the pretest and posttest were compared to further establish students' conceptual development on the concept of oxidation-reduction reactions. The themes were deduced from open coding and constant comparison of the reasons given by students for selection of any of the options to the 10 test items in the pretest and posttest.

Research Question 5 was answered using themes. That is the views of students on the use of the alternative approach (PTLA) in teaching oxidation-reduction reactions were open coded and compared constantly. Meanings were made of the given students' explanations after the open coding and constant comparison to come out with the themes. Samples of students' explanations and codes were used to support each theme.

CHAPTER FOUR

RESULTS AND DISCUSSION

The chapter looks at the results of the study and research questions for each of the stages of the design-based research approach serve as a guide to the presentation of the results. The results are presented first in tables and themes and samples of explanations from teachers and students which are used to support the findings. Discussions of the findings accompany the presentations of results.

Students' Alternative Conceptions and Other Difficulties in Oxidation-Reduction Reactions

Research Question 1 sought to find out chemistry students' alternative conceptions and other conceptual difficulties in oxidation-reduction reactions. The research question is in two parts. The first part sought to find out the students' difficulty in terms of performance using a diagnostic test of 18 items. The mean score of students in the diagnostic test was 18.7 (SD = 8.1) with minimum and maximum scores of 2 and 36 respectively out of the total score of 36 marks. Two-thirds of the 213 students scored marks ranging from 10.6 to 26.8. The standard deviation of 8.1 is high indicating a wide spread of students' scores. A large number of students involved in the study could be said to have difficulties in responding to test items on oxidation-reduction reactions. The study confirms difficulties of students in oxidation-reduction reactions seen in the WAEC results (WAEC, 2004; 2005; 2006; 2007; 2008; 2009; 2011; 2012; 2013). Students' difficulty leading to their weak performance could be attributed to the confusion associated with the concept of the four models of oxidation-reduction (Harrison & Treagust, 1998).

To further establish the difficulties of the students in responding to the diagnostic test items on oxidation-reduction reactions, percentages of the students' correct responses were calculated to establish the difficulty of students. The percentages of students' correct responses to each of the 18 test items are presented in Table 1.

Reduction half-reaction

From Table 1, Items 13, 14, 17, and 18 were less difficult as the difficulty index for each item was 0.8. For Item 13 which required students to identify the reduction half-reaction of the $Mg + Zn(NO_3)_2 \rightarrow Mg(NO_3)_2 + Zn$, majority of the students (76.5%) identified $Zn^{2+} \rightarrow Zn$ as the correct reduction half-reaction of the reaction, but 13.1% opted for $Mg \rightarrow Mg^{2+}$ as the reduction half-reaction, 2.3% opted for $Mg + Zn^{2+} \rightarrow Mg^{2+} + Zn$ as the reduction half-reaction, and 8.0% of the students opted for none of the three options.

For Item 17, 74.6% of the students correctly identified the reduction half-reaction of $Fe^{2+} + Cr_2O_7^{2-} \rightarrow Fe^{3+} + Cr^{3+}$ as $Cr_2O_7^{2-} \rightarrow Cr^{3+}$, but 16.0% opted for $Fe^{2+} \rightarrow Fe^{3+}$ as the reduction half-reaction and 9.4% failed to respond to Item 17. The results of Items 13 and 17 show that it was less difficult for the students to deduce the reduction half-reaction from a full or an ionic equation of oxidation-reduction reaction.

Table 1- *Percentage of Students' Correct Responses in the Diagnostic Test (N = 213)*

Item	n	%	ρ
13	163	76.5	0.8
18	160	75.1	0.8
14	159	74.6	0.8
17	159	74.6	0.8
15	154	72.3	0.7
16	146	68.5	0.7
2	115	54.0	0.5
7	103	48.4	0.5
5	99	46.5	0.5
12	98	46.0	0.5
8	95	44.6	0.5
10	91	42.7	0.4
9	89	41.8	0.4
6	83	39.0	0.4
4	81	38.0	0.4
1	78	36.6	0.4
3	68	31.9	0.3
11	46	21.6	0.2

Where n = the total number of the students who scored each item correct

Source: Field survey, Adu-Gyamfi (2013)

This means that though students have difficulty with the concept of oxidation-reduction reaction in general, deducing reduction half equations was less difficult for them. It could be that all the reduction half-reactions involved oxygen atoms. This is because students usually appreciate and conceptualise oxidation-reduction reactions best using addition and removal of oxygen model (Barke, 2012).

Alternative conceptions: Reduction half-reaction involves loss of electrons. An excerpt is: "because $Cr_2O_7^{2-}$ losses electron and became Cr^{3+} which made it reduction half reaction" (129).

Reduction half-reaction involves decrease in oxidation state as a result of loss of electrons. An excerpt is: "$Zn^{2+} \rightarrow Zn$; because reduction half is the loss of electron. That is there is a decrease in oxidation state, from +2 state to +3 state" (057).

Reduction half-reaction involves reduction in ionic charge. An excerpt is: "because Zn^{2+} decrease to Zn. Meaning there is a decreased in the charges and that makes Zn^{2+} goes through reduction" (090).

Reduction half-reaction involves the released of 'positive' charges at the product side of reactions. An excerpt is: "$Fe^{2+} \rightarrow Fe^{3+}$; because it has release a charge of +3 at the product side" (149).

Other conceptual difficulties: Students had difficulty in conceptualising gain of electrons in reactions. It was considered as increased in the charge on atoms involved in reactions. An excerpt is: "Fe^{2+} has gain electron to form Fe^{3+} which means there is an increase in electron and is reduced" (182).

Oxidation half-reactions

For Item 18, 75.1% of the students correctly identified the oxidation half-reaction of $Fe^{2+} + Cr_2O_7^{2-} \rightarrow Fe^{3+} + Cr^{3+}$ as $Fe^{2+} \rightarrow Fe^{3+}$, but 15.5% of the students opted for $Cr_2O_7^{2-} \rightarrow Cr^{3+}$ as the oxidation half-reaction and 9.4% of the students gave no response. For Item 14, 74.6% of the students correctly identified $Mg \rightarrow Mg^{2+}$ as the oxidation half-reaction of $Mg + Zn(NO_3)_2 \rightarrow Mg(NO_3)_2 + Zn$, but 13.1% of the students identified $Zn^{2+} \rightarrow Zn$ as the oxidation half-reaction and 1.4% of the students identified $Mg + Zn^{2+} \rightarrow Mg^{2+} + Zn$ as the oxidation half-reaction as well as 10.8% of the students failed to select an option as oxidation half-reaction. The results of Items 14 and 18 show that it was less difficult for students to identify the oxidation half-reaction from a full or an ionic equation. This is because the students can identify the reduction half-reactions and thereby the remaining from either full or ionic equation is the oxidation half-reaction.

Alternative conceptions: oxidation half-reactions involve decrease in oxidation number. An excerpt is: "because the oxidation number in the reactant side decreased after the equation at the product side" (105).

Oxidation half-reactions involve gain of electrons. An excerpt is: "the one which undergoes oxidation is the oxidation half which has gain electrons; and change from 1 to +2 that is Mg^{+} to Mg^{2+}" (072).

Oxidation half-reaction involves loss of oxygen atoms. An excerpt is: "$Cr_2O_7^{2-} \rightarrow Cr^{3+}$ because its oxygen has been taken out" (152).

Oxidation half-reaction involves removal of oxygen and increase in oxidation state. An excerpt is: "in this reaction, $Fe^{2+} \rightarrow Fe^{3+}$; because there has been removal of oxygen and increment of oxidation number of iron" (105).

Oxidation half-reaction involves gain of electrons to increase oxidation state of atoms. An excerpt is: "oxidation half is the gain of electrons. That is there is an increase in oxidation state of Mg from 0 state to +2 state" (131).

Oxidation half-reaction involves gain of ionic charge. An excerpt is: "Mg has gain a charge of +2 in Mg^{2+}" (005); and "since the charge of Fe increase from +2 to +3" (067).

Oxidation half-reaction involves decrease in ionic charges. The excerpts were: $Zn^{2+} \rightarrow Zn$; because it reduces a charge of +2 to zero" (057); and "because zinc has reduced the charge of +2 to zero (0) charge" (062).

Oxidation half-reaction involves increase in ionic charges. The excerpts were: "$Mg \rightarrow Mg^{2+}$; since the charge in the reactant has increased" (031); and "$Fe^{2+} \rightarrow Fe^{3+}$; because of the charge in the reactant has increased" (180).

Oxidation half-reaction involves gain of electrons and oxygen atoms. An excerpt is: "$Mg \rightarrow Mg^{2+}$ is the answer because Mg gained electrons and also oxygen was added" (012).

Other conceptual difficulties: students had difficulty deducing and explaining the oxidation state of atoms (substances) involved in oxidation half-reactions. Examples are: "$Mg \rightarrow Mg^{2+}$ because the oxidation number has increased at the product side" (107); and "Fe^{2+} is oxidation half because it increased in oxidation state" (116).

Ionic equation

From Table 1, Items 15 and 16 were also less difficult to the students. This is because the calculated difficulty index for each of the two items was 0.7. For Item 15, 72.3% of the students identified $Mg + Zn^{2+} \rightarrow Mg^{2+} + Zn$ as the correct overall ionic equation for $Mg + Zn(NO_3)_2 \rightarrow Mg(NO_3)_2 + Zn$, but only 4.2% and 6.1% of the students incorrectly identified $Mg \rightarrow Mg^{2+}$ and $Zn^{2+} \rightarrow Zn$ as overall ionic equation respectively and 17.4% of the students failed to identify any of the options as the overall ionic equation. The results of Item 15 show that it was less difficult for students to deduce the overall ionic equation for a full chemical equation. This could be attributed to the fact that it was less difficult for students to identify the oxidation half- and reduction half-reactions of the given chemical equations. Hence, assembling the two to form the overall ionic equation could not have been difficult either.

Other conceptual difficulties: students had difficulty in conceptualising ionic equation using oxidation state or electron transfer. This is because students could only deduce half equation but not overall ionic equation. For example: "Mg oxidises to Mg^{2+} hence oxidation number changes from 0 to +2" (051); and "$Zn^{2+} \rightarrow Zn$ is the ionic equation as Zn lost electrons" (126).

Spectator ion

For Item 16, 68.5% of the students found it less difficult to identify NO_3^- as the spectator ion of $Mg + Zn(NO_3)_2 \rightarrow Mg(NO_3)_2 + Zn$, but 8.0% and 6.6% of the students identified Mg^{2+} and Zn^{2+} respectively as the spectator ions of the reaction and 16.9% of the students found it difficult to provide any ion as the spectator ion. The results of Item 16 could be attributed to the fact that the students were able to identify the half-reactions as well as the net ionic equation and hence, conceptualising spectator ion is less difficult to students.

Alternatives conceptions: spectator ions accept electrons. The excerpts are: "Mg^{2+}; this is because the ion gains electrons" (006); and "NO_3^-; because it has gain electron and has negative charge ion" (139).

Other conceptual difficulties: students had difficulties in conceptualising spectator ion using oxidation state of atoms. The "NO_3^-; because in balancing the chemical equation and finding its oxidation number it has a charge of +1 which is not written" (142); and "Mg^{2+} has positive oxidation state" (168).

Students had difficulties in deducing spectator ions as ions with no net effect. An excerpt is: "Zn^{2+} is a spectator ion because it does not take part in the reaction" (084).

Species oxidised

The results from Table 1 further show that Items 2, 5, 7, and 8 were difficult to the students. This is because the difficult index for this area was 0.5. For Item 2, 54.0% of students identified Zn as the specie oxidised in $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$, but 16.4% identified $CuSO_4$, 15.0% identified $ZnSO_4$, 12.2% identified Cu as the specie oxidised in the reaction and 2.3% failed to provide the specie which was oxidised. The Item 6 was also used to find out the difficulty of the students in identifying a specie oxidised in $Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$. The results show that 61.0% of the students found it very difficult to identify Br^- as the substance oxidised in the reaction and the difficulty index was calculated as 0.4. Out of the 61.0% students, 18.3% identified Cl_2, 4.7% identified Cl^-, 26.8% identified Br_2 as oxidised and 11.3% failed to provide any specie as oxidised in the reaction. The results of Items 2 and 6 show that it was difficult for the students to deduce species that were oxidised in oxidation-reduction reaction involving metals (that is substances formed through purely ionic bonding) but very difficult when substances involved were non-metals (that is substances formed through purely covalent bonding). This could be that the students found it difficult identifying which specie was causing another specie to oxidise (Osterlund & Ekborg, 2009).

Alternative conceptions: oxidised species decrease in oxidation state. An excerpt is: "Cl_2 is oxidised as there is a decreased in its oxidation number" (035).

Oxidised species accept electrons in reactions. The excerpts are: "the answer is Br^- because it accepts an electron to become Br_2" (052); and "Zn is oxidised because Zn has accepted electrons" (149).

Oxidised species contain oxygen atoms. An excerpt is: "$ZnSO_4$; this is because there is an increase in oxygen. Oxidation is defined as the gain of oxygen" (213).

Oxidised species loss oxygen atoms in reactions. The excerpt are: "Cu is oxidised because it decreased in the number of oxygen atoms" (013); and "$CuSO_4$ is oxidised because it has lost oxygen at the product side" (208).

Oxidised species in reactions have oxygen atoms removed resulting in decreased in oxidation state of other atoms. The excerpts are: "Cu; this is because oxygen has being removed from it and thus has reduced in oxidation state" (085);

and "Cl^-; this is because the oxidation state of it is reduced by the removal of oxygen from it making it oxidised" (195).

Oxidised species accept electrons to decrease in oxidation state. The excerpts are: "$CuSO_4$ is oxidised because it decreased in oxidation number and accepted electron ..." (103); and "Cl_2; this is because it has gained electron, and reduced in oxidation number" (212).

Oxidised species increase in ionic charge. The excerpts are: "Cu; because from the reactant side, the charge of $CuSO_4$ equals 0 but at the product side Cu is not equal to 0" (159); and "Br_2 is the answer because in the reactants Br has a charge of -2 but in the products Br has a charge of +2" (145).

Oxidised species gain electrons to increase ionic charge. An excerpt is: "$CuSO_4$ is oxidised because it will be the one which will be gaining electron to increase charges from the others" (199).

Oxidised species loss electrons to change ionic charges. An excerpt is: "Br^- is the answer; because it lost electron to change its charge to neutral" (191).

Oxidised species accept hydrogen atoms and lose oxygen atoms. The excerpts are: "Zn; because oxidation is the substance that accepts hydrogen and donates oxygen in a redox reaction" (176); and "Cl^- is oxidised and it losses oxygen and will gain hydrogen" (063).

Other conceptual difficulties: student consideration of the moles as having effect on the oxidation state of atoms in reactions. The excerpts are: "$2Br^-$ undergoes oxidation by increasing in oxidation number from -2 to 0 but increase in oxidation defined oxidation" (094).

Students had difficulties in seeing that the atoms in the reactant side transfer electrons but not those in the product side of reactions. An excerpt is: "the answer is Br_2 because of $2Br^- \rightarrow Br_2 + 2\breve{e}$. Since the Br_2 gains electrons, it becomes oxidised" (066).

Student had difficulty in seeing that atoms (substances) at the reactant side are oxidised by increasing in oxidation state but not those at the product side of reactions. The excerpts are: "the answer is Br_2 because there is an increased in oxidation number" (046); and "$ZnSO_4$ is the correct answer because the oxidation number has been increased from 0 to +2" (048).

Students had difficulties in using the combined concept of oxidation state and electron transfer to conceptualise oxidised species. An excerpt is: "oxidation is the removal of electrons and Cl_2 has lost electrons to become Cl^- with 0 oxidation state" (117).

Species reduced

For Item 7, 48.4% of the students found it less difficult to identify Cl_2 as the substance reduced in $Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$, but 15.5% identified Br^-, 16.9% identified Cl^-, 8.9% identified Br_2 as the specie reduced in the reaction and 10.3% of the students failed to provide any specie they thought was reduced. Item 3 on reduced species was very difficult with calculated index of 0.3. The results show that only 31.9% of the students identified Cu^{2+} in $CuSO_4$ correctly as the substance reduced in $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$, but 22.5% identified Zn, 5.2% identified $ZnSO_4$, 36.6% identified Cu as the substance reduced and 3.8% of the students provided no specie as reduced in the reaction. The results of Items 3 and 7 show that it was very difficult for students to identify species reduced in full or net ionic equations as well as substances involve in reactions of ionic bonding or covalent bonding. This could be that the students found it difficult to identify the specie in the reaction causing the reduction contrarily to what is being reported elsewhere that students find it easy to identify reducing agents (Osterlund & Ekborg, 2009).

Alternative conceptions: reduced species increase in oxidation state. An excerpt is: "Cl_2 has increased in oxidation state at the product side thus Cl_2 is said to be reduced in the reaction" (056).

Reduced species lose electrons in reactions. An excerpt is: "Cl^- is reduced because it was neutral at the reactant side and it lost electron at the product side and became Cl^- which made it reduced" (192).

Reduced species lose electrons to change ionic charges. An excerpt is: "$ZnSO_4$ will be my answer. This is because it has lost electrons to change the charge to +2" (011).

Reduced species lose electrons as a result of loss of oxygen atoms. An excerpt is: "Br_2 is the answer because it loss electrons from loss of oxygen" (131).

Other conceptual difficulties: students had difficulty in identifying that the atoms (species) in the reactant side of reactions were reduced instead of the product side. The excerpts are: "$ZnSO_4$; because it is decreasing in oxidation number" (088); and "Br^-; is reduced in this reaction, because of the decreased in oxidation state from $2Br^-$ to Br_2" (106).

Students had difficulty in seeing that a positive charge was indication of loss of electron but not gain of electron. An excerpt is: Zn; Zn $\rightarrow$ Zn^{2+} which means Zn has gain electron and hence is reduced and from the definition, reduction is the gain of electron" (128).

Students had difficulty in conceptualising reduced species as species from which oxygen atoms were removed. That is what should be considered as removal of oxygen atoms. An excerpt is: "$ZnSO_4$; because 4 oxygen atoms can be removed from the compound to get ZnS" (150).

Students had difficulty in conceptualising the transfer of hydrogen model as the concept was used even when there was no hydrogen atoms directly involved in the reactions. An excerpt is: "Cl^- is the answer because it gains hydrogen from the reactants to form Cl^- in the products" (119).

Students had difficulty in conceptualising species reduced in reactions using the combined concept of oxidation state and electron transfer. The excerpts are: "Zn; at the reactant side have no oxidation number but at the product side have gain electrons" (111); and "Br^-; this is because it has lost electron, and increased in oxidation number" (138).

Students had difficulty conceptualising reduced species using ionic charge. The excerpts are: "Zn; comparing Zn and $ZnSO_4$ with respect to charges, Zn is not equal to 0 but $ZnSO_4$ equals to 0" (067); and "Br^-; the charge is increased from 0 to -2. (024).

Reducing agents

Item 5 was difficult with an index of 0.5. This is because 46.5% of the students identified Zn as the reducing agent in $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$, but 16.9% identified $CuSO_4$, 6.1% identified $ZnSO_4$, and 21.6% identified Cu as the reducing agent and 8.9% of the students provided no response as the reducing agent of $CuSO_4$ in the reaction. For Item 9, 41.8% of the students found it less difficult to identify Br^- as the reducing agent of $Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$ with item difficulty index calculated as 0.4. However, 23.5% of the students identified Cl_2, 13.6% identified Cl^-, and 8.9% identified Br_2 as the reducing agent and 12.2% of the students could not provide any response as the reducing agent. The results of Items 5 and 9 show that the students found it difficult and not easy to identify the reducing agent from any given oxidation-reduction reaction (Osterlund & Ekborg, 2009). This could be the reason why the students found it difficult to deduce any substance reduced in a given oxidation-reduction reaction as seen above.

Alternative conceptions: reducing agents are species that have their oxidation state reduced in reactions. The excerpts are: "Cl^-; is a reducing agent because it has reduced in its oxidation state" (085); and "$ZnSO_4$; it is a reducing agent because it decreases in oxidation number" (178).

Reducing agents are atoms (species) that accept electrons in reactions. The excerpts are: "Br^-; because of addition of electrons to Br^-" (031); and "$CuSO_4$; is reducing agent because it has gain electron" (118).

Reducing agents are species in reactions with no oxygen atoms bonded to. An excerpt is: "my answer is Zn and Cu as they have no oxygen but they take oxygen later" (009).

Reducing agents cannot accept hydrogen atoms because they have already increased in oxidation state. An excerpt is: "the answer is $CuSO_4$ because it cannot take on hydrogens because the oxidation number of Zn had increased" (184).

Reducing agents accept electrons and lose oxygen atoms. The excerpts are: "Zn; addition of electrons and loss oxygen atom to a substance makes it a reducing agent" (134); and "Br_2; there is removal of oxygen and it's gaining electron" (202).

Other conceptual difficulties: students had difficulty in using the combined concept of oxidation state and transfer of oxygen atoms. The excerpts are: "Zn is reducing agent because it caused element to undergo oxidation process thereby making the element accept oxygen and also increase the oxidation state of that element" (016).

Students had difficulties in conceptualising reducing agents using the concept of oxidation number and electron transfer. An excerpt is: "the answer is Br_2 because it accepts electrons produced from Cl_2 making Cl_2 reduced. That is Br_2 decreased in oxidation number" (061).

Students had difficulties in conceptualising reducing agents using ionic charge. An excerpt is: "Cu on the reactant side has a charge of +8 by calculation but on the product side Cu has a charge of zero (0) and it is therefore reducing agent" (008).

Students had difficulties in conceptualising reducing agents as atoms (species) oxidised in reactions. The excerpts are: "$CuSO_4$ is a reducing agent because it causes the reduction of Zn and is oxidised itself" (174); and "Cl_2; because Cl_2 has oxidised and reducing agent is a substance in a redox reaction that undergoes oxidation" (036).

Oxidising agent

For Item 4, only 38.0% of the students found it less difficult to identify $CuSO_4$ as the oxidising agent of Zn in $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$ with item difficulty index of 0.4. However, 22.5% of the students identified Zn, 15.0% identified $ZnSO_4$, 16.9% identified Cu as the oxidising agent, and 7.5% of the students failed to identify any of the species as oxidising agent. Item 8 had difficulty index of 0.5 and 44.6% of the students identified Cl_2 as the correct oxidising agent in $Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$, but 22.1% identified Br^-, 8.0% identified Cl^-, 11.3% identified Br_2 as the oxidising agent, and 14.1% of the students could not identify any species as the oxidising agent. The results of Items 4 and 8 show that it was difficult for the students to identify an oxidising agent (Osterlund & Ekborg, 2009) in a full or net ionic equation as well as purely covalent or ionic boning forms of oxidation-reduction reaction.

Alternative conceptions: oxidising agents help to deduce the oxidation state of atoms in oxidation reactions. An excerpt is: "Br^- is an agent helping us to find the oxidation state of oxidation reactions" (078).

Oxidising agents are atoms (species) oxidised by loss of electrons. The excerpts are: "$CuSO_4$; because it was oxidised at the reactant side and losses it electron at the product side, thus it made the Zn oxidised which makes it an oxidising agent" (104); and "Cl_2; it oxidises (ie, give out electrons to the $2Br^-$ on the reactant side, and oxidising agent donates electrons" (124).

Oxidising agents accept oxygen atoms to result in change in oxidation state. The excerpts are: "$ZnSO_4$; because it received the oxygen so therefore is the oxidising agent. This is because in Zn the oxidation number was +2 but in $ZnSO_4$ its oxidation number is 0" (207); and "Br_2 is oxidised due to the addition of oxygen that caused increased in its oxidation state" (025).

Oxidising agents donate electrons and oxygen. The excerpts are: "$CuSO_4$; it has lost SO_4^{2-} to Zn atom. Removal of oxygen atom" (004); and "Br^-; there is an addition of oxygen and its gaining electron" (119).

Other conceptual difficulties: students had difficulty in identifying oxidising agents using the concept of oxidation numbers. An excerpt is: "Br_2 is an oxidising agent because its oxidising number decreased from +7 to 0" (006).

Students had difficulty in seeing atoms that gain electrons in reactions. An excerpt is: "Br_2; it has gain electron" (211).

Students had difficulty using ionic charge to conceptualise oxidising agents. The excerpts are: "Cu; it has charge of positive which make it oxidising agent" (018); and "Br^-; because it has reduced the charge of Cl_2^+ to $2Cl^-$" (198).

Students had difficulty conceptualising oxidising agents using the combined concept of oxidation and ionic charge. An excerpt is: "Cu; because in

The presence of hydrogen atoms in reactions makes such reactions oxidation-reduction reactions. An excerpt is: "because 2HCl has lost the hydrogen to form $ZnCl_2$ in $2HCl + Zn(OH)_2 \rightarrow ZnCl_2 + 2H_2O$" (193).

In reactions, removal of oxygen atoms from species results in oxidation state of the other atoms. An excerpt is: "the reaction $2HCl + ZnO \rightarrow ZnCl_2 + H_2O$ is a redox reaction because there is an increase in the oxidation number of hydrogen because of removal of oxygen" (103).

Other conceptual difficulties: students had difficulty in determination of the correct oxidation state of atoms involved in a given reaction. The excerpts are: "because the oxidation number of Zn decreases from -2 to +2" (015), and "because Cl changes from -2 in HCl to +1 state in $ZnCl_2$ and Zn changes from 2" (115).

Students had difficulty in explaining the change in oxidation state of species being reduced or oxidised in a reaction. An excerpt is: "there is changed in oxidation number of HCl and $ZnCl_2$" (144).

Students had difficulty in conceptualising oxidation-reduction reactions using the oxygen transfer model. It was used even when there was no oxygen atoms involved in the reactions. An excerpt is: "$2HCl + Zn \rightarrow ZnCl_2 + H_2$ is a redox reaction because oxygen is not in or oxygen has been removed from it" (142).

Students conceptualised oxidation-reduction reactions as simultaneous reactions of oxidation and reduction processes but had difficulty in showing both processes in the given reactions. The excerpts are: in $2HCl + Zn(OH)_2 \rightarrow ZnCl_2$

+ $2H_2O$, "redox reaction is when both oxidation and reduction are occurring simultaneously" (118); and "because it has both oxidation and reduction" (203).

The results show that students' alternative conceptions were in (i) identification of oxidation-reduction reactions, (ii) oxidised and reduced species, (iii) oxidation half-reactions, (iv) reduction half-reactions, and (v) overall ionic equations. The alternative conceptions, such as reduction half-reaction involves loss of electrons; oxidation half-reaction involves decrease in oxidation number; oxidised species contain oxygen atoms; reduced species lose electrons as a result of loss of oxygen; and in combustion, the presence of heat introduces oxygen atoms, are classroom related (Osman & Sukor, 2013). This is because oxidation state (number), electron transfer, oxygen and hydrogen transfer are models of oxidation-reduction reactions which are learnt in the classroom.

Students' alternative conceptions were partly due to students' use of the concept of loss and gain of oxygen or hydrogen. Students used these concepts to conceptualise reactions where there was no change in the oxidation state of the atoms involved or transfer of electrons as oxidation-reduction reactions. This means students felt comfortable using the loss and gain of oxygen or hydrogen models of oxidation-reduction reactions (Barke, 2012).

Students' alternative conceptions such as reducing agents accept electrons and lose oxygen atoms; oxidising agents accept oxygen atoms to result in change in oxidation state; and oxidised substances accept electrons to increase ionic charge and other conceptual difficulties were due to the use of combined concepts of the four models of oxidation-reduction reactions. The combined concepts included oxidation number and electron transfer; oxidation number and oxygen transfer; electron transfer and oxygen transfer; oxidation number and ionic charge; and electron transfer and ionic charge. This could be due to misunderstanding, miseducation or misapplication (Wenning, 2008) of the four models of oxidation-reduction reactions. Hence, students were confused in using more than one model of oxidation-reduction reaction (Harrison & Treagust, 1998) to conceptualise any aspects of chemical reactions.

Other conceptual difficulties existed in identifying a particular reaction as an oxidation-reduction type, a specie as oxidised or reduced, and as oxidising agent or reducing agent using the four models of oxidation-reduction reactions. In the case of oxidation number, students could not explain which atom (specie) was decreasing or increasing in oxidation state and even where they were able, the students cannot determine the correct oxidation state of the atoms. In situations where the given reaction was not oxidation-reduction reaction or the given specie was not oxidised or reduced, and not oxidising agent or reducing agent students made explanations by just saying the oxidation state of the atom has changed, decreased, or increased. This shows that it is difficult for students to conceptualise oxidation-reduction reaction using the oxidation number.

It was difficult for students to conceptualise oxidation-reduction reactions in terms of electron transfer (De Jong et al., 1995) and even notwithstanding the number of times they did try they still had difficulty in explaining oxidation-reduction reaction using the concept of electron transfer (Osterlund & Ekborg, 2009). Though the use of the concept of transfer of electrons led some students to identify a given reaction as oxidation-reduction reaction and to deduce species being oxidised or reduced as well as oxidising or reducing agent in reactions, in most instances they could not explain the concept of transfer of electrons very well. That is the number of electrons transferred and the direction of the electron flow (that is gaining or losing electrons) to achieve such results. The chemistry is that the gain or loss of electrons should be from the reactant side to the product side of the chemical equation so represented.

Students' conception of oxidation-reduction reaction as a simultaneous reaction involving oxidation and reduction processes was interesting to note. Students, however, shared conceptual difficulties. This is because in most instances students could not explain where the oxidation or the reduction was but only justified that the identified reaction was a simultaneous reaction. This seems to suggest that the students conceptualise oxidation-reduction reactions as reactions where the oxidation and reduction reactions occur at the same but not as reported elsewhere that students' difficulties in oxidation-reduction reaction are as the result of the fact that they consider oxidation and reduction processes as mutually exclusive reactions (Osterlund & Ekborg, 2009).

The results further show that students conceptualised oxidation and reduction processes using ionic charge. This concept contributed to students' alternative conceptions and other conceptual difficulties. The difficulty here was that students cannot distinguish between oxidation number and ionic charge of species involve in reactions. It must be emphasized that in some simple ions the oxidation number and the ionic charge were the same but in complex ions such as the oxoanions they are not. It was also evident that students had difficulty in conceptualising moles of substances in a balanced chemical equation which wrongfully influence their determination of the oxidation number or ionic charge of species in chemical reactions.

Everyday application of oxidation-reduction reactions

Items 10, 11, and 12 diagnosed students' conceptual understanding on the application of oxidation and reduction processes in everyday life. The difficulty indices were 0.4, 0.2, and 0.5 respectively.

Rusting of metallic iron ship

For Item 12, 46.0% of the students found it less difficult to identify that the brownish colour developed on a metallic iron ship at the shore of the Atlantic Ocean in the presence of oxygen in an open air and carbonic acid was the result of oxidation-reduction reaction. However, 9.9% identified that combustion of iron has occurred, 15.5% identified that the iron metal has changed colour, and 28.6% could not even deduce what was going on. As much as oxygen was involved in the reaction does not make it strictly a combustion reaction and even combustion reaction is an example of oxidation-reduction reactions. The change in colour of iron though observable but cannot overshadow the oxidation-reduction reaction taking place on the surface of the metallic iron ship, which is the chemistry behind the change in colour.

Alternative conception: brownish colour was formed on iron metal by addition of hydrogen atoms. An excerpt is: "the brown colour is because a redox reaction has occurred and is because of chemical addition of hydrogen" (210).

Other conceptual difficulties: students had difficulties in conceptualising the role of atmospheric oxygen atoms in rusting of iron. An excerpt is: "a redox reaction has occurred because the oxygen helps in oxidising of iron to break it down to hydrated iron where CO_3^{2-} in H_2CO_3 helps to catalyse and reduce the property of the iron" (033).

Students had difficulties in conceptualising combustion as oxidation-reduction reaction. An excerpt is: "combustion reaction has occurred because oxygen supports combustion which changed the colour of the metallic iron" (206).

Students had difficulties in conceptualising rusting of iron as oxidation-reduction reaction as rusting was considered as a physical change. An excerpt is: "iron metal has changed colour because there is the presence of rusting" (151).

The results with respect to the development of rust on the surface of metallic iron being an oxidation-reduction reaction show that most of the students could not even associate the reaction with transfer of electrons. Even where the concept of oxidation number was used, some of the students found it difficult to explain the concept. The difficulty of students was their preference for the concept of transfer of oxygen and not considering combustion as an oxidation-reduction reaction. Though such students in the study usually deduced the correct response but could not explain the chemistry very well because not all oxidation-reduction reactions are caused by transfer of oxygen notwithstanding the presence of oxygen atoms in some reactions.

Reaction of copper envelope and frame

For Item 10, 42.7% of the students correctly identified that oxidation-reduction reaction occurred when an envelope of copper metal was heated with a flame to turn black on the outside while the inside remained copper-coloured. However, 24.9% identified that a combustion reaction has occurred, 3.8% identified that the outside of copper was made from black soot, 2.8% identified that the copper atom has changed colour when the envelop was heated, and 25.8% of the students could not provide any response as to what happened when copper envelope was heated with a flame. In the case of Barke (2012), most of the students identified the reaction as a black soot being formed from the outside of the copper envelop which was the detractor to the oxidation-reduction reaction taking place as compare to the current study. The presence of the flame once again could have attracted the attention of the students thinking that combustion was taking place and an obvious lack of conception of the role of oxygen made students accepted the black soot as actually what was happening instead of oxidation-reduction reaction.

Alternative conceptions: in combustion, the presence of heat introduces oxygen atoms. An excerpt is: "combustion reaction has occurred because the flame outside the copper metal added oxygen" (077).

Black soot from frame changes the colour of copper metal black. An excerpt is: "the outside was made from black soot because the outside copper the smoke of the flame is black. It will dust the outside of the copper" (178).

Copper metal changes colour when it loses electrons. An excerpt is: "this is because copper lost electron and then changed colour" (153).

Copper metal turning black in a frame is due to transfer of hydrogen atoms. An excerpt is: "A redox reaction has occurred because there was an addition of hydrogen as reduction and there was removal of hydrogen as the oxidation" (175).

Other conceptual difficulties: students had difficulties in conceptualising that addition of oxygen to substances causing combustion is a form of oxidation-reduction reactions and not just combustion. An excerpt is: "combustion reaction has occurred because it was burnt in the presence of oxygen" (051).

Students had difficulties in conceptualising copper metal heated in a frame as oxidation-reduction reactions using oxygen transfer but not release of electrons or increase in oxidation state of copper. An excerpt is: "a redox reaction has occurred since oxygen has been added to the copper metal as oxidation" (066).

Students faced difficulties in identifying and explaining oxidation and reduction processes as simultaneous processes. An excerpt is: "a redox reaction has occurred because both oxidation and reduction occurred simultaneously to balance each other thereby maintaining the colour of the copper metal" (113).

The results showed that students had difficulties in applying the concept of oxidation-reduction reactions. This is because there were very few instances where the students correctly conceptualised that oxidation-reduction reaction had occurred in the given process. Even with the idea that oxidation-reduction reaction has occurred, only few of the students' explanations could be related to change in oxidation state and transfer of electrons. Copper lost two electrons which was oxidation and the oxygen atom accepted the two electrons which was reduction or the oxidation number of copper increased from 0 to +2 which is oxidation and the oxidation number of oxygen decreased from 0 to -2.

The results further showed the difficulty of the students was their understanding of the heat from the flame, which they conceptualised that it introduced oxygen atom to oxidise the outside of copper to form an oxide of copper. This shows that the students' understanding of the role of oxygen in combustion is not clear (Barke, 2012). The process of copper metal turning black on the outside as a result of being heated was considered as physical but not a chemical process. This is not the correct chemistry. This was because the formation of the black colour was not just the deposition of soot.

Though the students realised that copper had lost electrons in the process they could not conceptualise the process as oxidation-reduction reactions. This was an indication that the students had difficulties in everyday application of the concept of oxidation-reduction reactions. These alternative conceptions and other conceptual difficulties demonstrated by students were as a result of simplistic association of chemical concepts (Talanquer, 2006).

Production of iron in blast furnace

For Item 11, only 21.6% of the students found it less difficult to identify that the production of iron in the blast furnace involving iron oxide and coal was oxidation-reduction reaction. However, 14.1% of the students identified that the carbon was a catalyst in the reaction, 26.8% of the students identified that the iron oxide has simply reduced, 9.4% of the students identified that the iron oxide has simply decomposed into its elements, and 28.2% even failed to provide any response. The percentage of the students who appreciated that the production of iron in the blast furnace was almost the same as that reported by Barke (2012) which is 20.0%. This could also be the case where students were being distracted by the presence of oxygen thinking that its being taking away from the iron oxide thereby reducing it to metallic iron and carbon dioxide or just carbon.

Alternative conceptions: carbon as a catalyst in a blast furnace reduces iron oxide by removal of oxygen atoms. An excerpt is: "the carbon as a catalyst reduces Fe_3O_4 by removing its oxygen" (008).

Iron in the iron oxide increased in oxidation state to form iron metal. An excerpt is: "a redox reaction has occurred because iron has gain in the oxidation number" (141).

Iron in blast furnace reduced by loss of electrons. An excerpt is: "the iron has reduced because iron oxide has decreased in electrons …" (128).

Iron oxide lost oxygen atoms to form iron metal in blast furnace. An excerpt is: "oxygen is removed in the iron oxide to produce only the iron, so redox reaction has occurred" (101).

Iron oxide was oxidised by carbon to form iron metal. An excerpt is: "a redox reaction has occurred because the iron oxide (Fe_3O_4) is being oxidised by the carbon into liquid iron" (207).

Iron oxide reduced in blast furnace as it changed its physical state. An excerpt is: "because iron oxide has changed from its original state to another iron oxide has lost it property as a metal to another state" (053).

Iron oxide reduced by the presence of glaring light. An excerpt is: "iron oxide has reduced; because the iron is running out with glaring means, the iron oxide has reduced" (182).

Other conceptual difficulties: students had difficulties in conceptualising production of iron in blast furnace as oxidation-reduction reactions because of the role of carbon. An excerpt is: "carbon was a catalyst; because addition of a suitable catalyst increases the rate of every reaction" (011).

Students had difficulties in identifying and explaining the atoms (species) that lost electrons in the blast furnace. An excerpt is: "a redox reaction has occurred because of the removal of an electron from a substance has occurred" (083).

Students had difficulties in conceptualising decomposition as oxidation-reduction reactions. An excerpt is: "iron oxide has decomposed into elements since the iron in the blast furnace is iron oxide and the coal (carbon) is necessary by heating" (162).

As much as it was true that the carbon (coal) was the catalyst in the reaction it cannot be considered as the main reason for the reaction. This is because the reaction would have occurred without the catalyst and hence iron was produced from iron oxide in the blast furnace by a certain chemistry which needed to have been explained instead of the catalysis aspect. Though the iron from the iron oxide reduced to form the iron metal but it is not necessarily by means of transfer of oxygen, change of physical state, decomposition into elements, or the given out of glaring light. The reduction is as a result of transfer of electrons which induces the change in oxidation state on iron. This then places the process in oxidation-reduction reaction but not just reduction. This is because wherever there is reduction reaction there is a simultaneous oxidation reaction. Hence, the students' alternative conceptions and other conceptual difficulties here were how to explain that the reduction of iron results in the oxidation of carbon with the oxygen from the injected air leading to the production of the iron metal in the blast furnace as in the following:

The oxidation state of carbon increased from 0 to +2 in carbon monoxide

$2C(s) + O_2(g) \rightarrow 2CO(g)$

The CO, the reducing agent reduces the iron ore (the magnetite, Fe_3O_4)

$Fe_3O_4(s) + 3CO(g) \rightarrow 3FeO(s) + 3CO_2(g)$

The second stage of the reduction is

$FeO(s) + CO(g) \rightarrow 3Fe(l) + CO_2(g)$

Teaching of Oxidation-Reduction Reactions

Research Question 2 sought to find out what make teachers ineffective in the teaching of oxidation-reduction reaction to their students. Four factors emerged from the study and these are:

(a) inhibition of instruction (which was any issue that militated against effective instruction of the concept);

(b) weak instructional strategy (which was any instruction that did not involve students collaborative learning in making meaning);

(c) difficult to teach concept (which was any demand the teaching of oxidation-reduction reactions placed on the shoulders of teachers); and

(d) teachers' professional development (which was any internal and external training that enhanced teachers' best practices).

Inhibition of instruction

On issues militating against instruction, the inhibitors were found as length of content; quality of students; and teacher's knowledge of concept and instructional strategies. From the number of years, the teachers have taught chemistry at the SHS level, it was obvious that they were not new to senior high school chemistry in general and the oxidation-reduction reaction in particular. This is because 33.3% of teachers had taught for 7 years, 16.7% for 9 years, 33.3% for 10 years, and 16.7% for 12 years. The teachers easily outlined the major aspects of oxidation-reduction reaction they usually taught as if they were copying from the actual chemistry syllabus (MOE, 2010; 2012).

Definitions of oxidation and reduction reactions using addition/removal of oxygen and hydrogen, oxidation number, and transfer of electrons;

Examples of redox reactions such as combustion and displacement reactions;

Reducing and oxidising agents;

Half reactions;

Balancing of redox equations in both acidic and basic media;

Redox titrations;

Electropotentials;

Electrolytic cells;

Electrolysis; and

Corrosion of metals.

The quality of students was identified to be a major factor that may or may not prolong the time for teaching oxidation-reduction reactions at the SHS level. It was found that in a class where majority of students were good and could work extra hard, teachers usually spent a few weeks to complete the oxidation-reduction reaction outline.

Out of the six teachers, 66.7% indicated they spent a lot of time in teaching oxidation-reduction reactions to students in a class which could be described as a weak one. For instance, Asare explained that

> "it takes long time to teach redox especially if the class is slow... it can take half of the term and the problem can be solved by taking it earlier with such students". (Teacher, School A)

Also, 33.3% of teachers interviewed felt that students' previous knowledge and experience determined the time for teaching the concept. For instance, Berko indicated that:

> "the foundation of the students prolongs the time period for the teaching. In one instant I used the whole term as I have to take care of what the students should have learnt before redox as well". (Teacher, School B)

In addition to this, teachers acknowledged that their own knowledge of the content and appropriate instructional strategy influenced the time taken to complete the teaching of oxidation-reduction reactions. Kyei, for instance, summed it all up as

> "if I know my subject matter very well and weaknesses of my students, I can easily select a strategy that will suit them. This will help to manage the number of weeks the topic will cover". (Teacher, School C)

In sum oxidation-reduction reaction was a lengthy area with a number of aspects to teach and learn. Though the area was lengthy there were other factors such as quality of students and teachers' knowledge of oxidation-reduction reaction and instructional that strategy may or may not prolong the time taking to complete it. Students are the materials available for teachers to impact knowledge and that it is the teacher's responsibility to guide them to make meaning of oxidation-reduction reactions. This can be achieved when the teachers transform the concept of oxidation-reduction reaction to the level of the students (Bond-Robinson, 2005; Mishra & Koehler, 2006). Hence, either the students are academically good or not teachers have to deploy the best pedagogical content knowledge that will suit their students.

Instructional strategies

It was generally accepted by teachers that their instructional strategy was very important in teaching oxidation-reduction reactions as 66.7% of teachers talked about teacher-led strategies and 33.3% talked about practical lessons and ability grouping. The selection of a particular instructional strategy was linked to students' characteristics. According to Sekyere,

> "teaching methods is important here but I need to understand and appreciate first the strength and weakness of my students ahead of the concept." (Teacher, School C)

The number of instructional strategies identified were categorised as formal and informal. These were lecture, questions and answers, reading assignments, practical lessons, problem-solving, ability groups, and "I do-you do-we do". Four of the teachers who used teacher-led strategies agreed that the concept of oxidation-reduction reactions using addition and removal of oxygen or hydrogen, oxidation number, and transfer of electrons was usually taught to students using the lecture method. The lecture method was not only used as the instructional strategy at the introductory stage of oxidation-reduction reaction but also used in presenting almost all the theoretical aspects of the concept by the teachers. The lectures were interspersed with reading assignments and "questions and answers" sessions.

One of the teachers, on the other hand, explained that all aspects of oxidation-reduction reactions should be taught through practical activities. However, where materials and equipment were not available for practical lessons other strategies other than the lecture method could be used. He indicated that one of such strategies was the use of ability groups. The following was an extract of an interaction with Kyei:

Researcher: Do you also use lecture in teaching redox reaction?

Kyei: No; I use ability groups.

Researcher: What is ability group?

Kyei: I try to identify the students who are good and mixed them with weak ones.

Researcher: What happens next?

Kyei: They do peer teaching after each lesson.

Researcher: Why peer teaching?

Kyei: This is because some students learn better with their colleagues teaching them.

Amakye on his part used the strategy he has termed "I do-you do-we do". In the strategy he first solved a given problem, gave students another problem to solve, and then solved a final one together with the students. He described the strategy as purely problem-solving. According to him:

> "usually my students are excited about how redox is presented to them and individual students are willing to be first to solve the next problem". (Teacher, School A)

Thus, teachers used various instructional strategies to teach oxidation-reduction reactions based on the quality of students and the resources available to the teacher. The teachers appreciated that no one instructional strategy was good enough for all students (Landcare Research, 2002; Osborne, 1993) and that they needed to vary their instruction with respect to content, lesson objectives, and students' characteristics (Bednar, Cunningham, Duffy, & Perry, 1995; Cooperstein & Kocevar-Weidinger, 2004; Wilson & Peterson, 2006) as no one instructional strategy is either right or wrong (Brown, 2005).

Difficult to teach concept

The teachers interviewed noted that the teaching of oxidation-reduction reactions at the SHS level placed some demands on teachers. This made the teaching of oxidation-reduction reactions difficult. Oxidation-reduction reaction was an important area for high school chemistry examination conducted by WAEC. Questions could be set on the theoretical aspect or the practical aspect especially in redox titration. Hence, the demand for teachers to teach the concept at all cost. The WAEC questions usually restricted students to the use of transfer of electrons and oxidation number models which seemed difficult to teach to most students. The following was an extract of an interaction with Asare:

Researcher: Why are you saying that the demands of WAEC make teaching of redox difficult?

Asare: WAEC questions on redox are standard as it calls for students thinking.

Researcher: But that is good?

Asare: Yes; but WAEC most at times ask questions on the transfer of electrons and oxidation number.

Researcher: But the two are both models of redox reactions?

Asare: Yes; but the oxidation number and transfer of electrons are usually difficult to teach to most students and you know that demands extra work from the teacher.

Another difficulty of teaching students was in the area of predicting an oxidation-reduction reaction by inspection. The teachers linked the students' inability to predict oxidation-reduction reactions to lack of knowledge of mapping, lack of mathematical knowledge, and difficulty in calculating and comparing oxidation state of the atoms. For instance, Amakye explained that the difficulty he faced in teaching oxidation-reduction reaction was "teaching students to predict redox reaction by mathematical inspection". (Teacher, School A)

Berko added that

> the difficulty I face in teaching redox is the students' inability to calculate and compare the oxidation numbers of atoms involved in reaction… as no matter what I do they go back to their old ways of calculating oxidation numbers. (Teacher, School B)

Three of the teachers identified that there was a difficulty in teaching the concept of balancing oxidation-reduction reactions using the ion-electron method. This method was reported to be used whenever the reaction occurred in acidic or basic medium. Such oxidation-reduction reactions involved the oxoanions like $Cr_2O_7^{2-}$. The difficulty was partly associated with the fact that students usually got confused with balancing in acidic medium and balancing in basic medium. The following was an extract in relation to balancing of oxidation-reduction reactions:

Researcher: Which other aspect of redox reaction is difficult to teach?

Kyei: Balancing of redox reactions.

Researcher: You said "balancing of redox"?

Kyei: Yes; especially balancing in acidic and basic medium.

Researcher: Why is it difficult to teach?

Kyei: The rules for balancing in acidic medium confuse students with the rules for balancing in basic medium.

According to Sekyere

> "the difficulty with teaching balancing redox is the students' inability to identify whether a given redox reaction is in acidic medium or basic medium". (Teacher, School C)

The basic mathematics with respect to the calculation of the number of moles of the atoms, charges, and electron was identified as another student challenge that made the teaching of balancing oxidation-reduction reactions difficult to teachers. For instance, Berko explained that

> "teaching students to overcome their challenge in inspecting and balancing the number of moles of the species in the ionic equation. ...especially balancing the charges". (Teacher, School B)

Two teachers who commented on practical lessons as the appropriate instructional strategy for the teaching of oxidation-reduction reactions identified another difficulty of teaching the concept. The difficulty was about inadequate materials and equipment in the high schools for the practical lessons.

Researcher: What challenge have you so far encountered in teaching redox reactions?

Kyei: Practicals; that is it, practicals.

Researcher: What about practicals?

Kyei: Inadequate materials and equipment such as reagents and salt bridge for teaching practicals.

Researcher: Have you inform your school administration about that?

Kyei: Yes off course but the usual complaint; no money.

Researcher: Does that mean you don't take your students through practicals?

Kyei: Not necessarily. There are times I have to improvised and at times I have to take my students to any of the sister schools where possible.

In summary, it could be seen that the external examination requirements which limited the students to the use of electron transfer (WAEC, 2008) placed a demand at the door steps of the teachers as the concept seem difficulty to teach to students. To be efficient in the area of chemical reactions is to be able to predict a given reaction and one of the demands facing the teaching of oxidation-reduction reaction was the difficulty in teaching students to predict a given reaction. Another result relating to the demands the teachers face in teaching oxidation-reduction reactions was to help students in determination of the number of moles of atoms, charges, and electrons (WAEC, 2005). It becomes difficult for students to balance oxidation-reduction reactions in basic and acidic media using the ion-electron method if they cannot determine the number of moles of the atoms, charges, and electrons. This could be that teachers themselves have a difficulty in explaining the transfer of electron model (De Jong et al., 1995) or they cannot select the appropriate instructional strategy for teaching the concept. This is because a good number of students construct meaning of concepts in similar way as they are taught by their teachers (Taber, 2011).

Teachers' professional development

The idea of professional development came up for discussion as the teachers lamented on the concept as difficult to teach. The teachers noted that the few in-service training they had participated in were helpful but the concepts and skills acquired were not entirely used due to lack of appropriate materials and equipment. The following was an extract from one of the teachers on in-service training:

Researcher: Do you usually receive support for teaching redox?

Amakye: What kind of support are you referring to?

Researcher: Training.

Amakye: Oh yes! I do attend in-service training organised by GES or GAST.

Researcher: How relevant are such trainings to you?

Amakye: They help a lot. I sometimes employed the ideas and skills from the training in teaching and at times not.

Researcher: Did you say "at times not"?

Amakye: Yes, because at times the ideas and skills are not new or can only be used when the need arises or there are no resources to help implement it.

Though the teachers were happy with the in-service training they had attended they were not happy with the frequency with which they had been given the opportunity to attend. That is the number of times they had attended in-service training were so few. For instance, Kyei explained that:

"I like the practical in-service training I attended. If it is done every month, I will be happy. But I have only attended in-service training on two occasions". (Teacher, School C)

Wireko added:

"I don't remember the last time I attended in-service training but the one I attended was good and I acquired some knowledge from it". (Teacher, School B)

The teachers teaching chemistry from each school were few and they hardly met to discuss issues relating to the teaching of chemistry. They only discussed issues bothering on science when they met at the departmental level to look at science in general. The following was an extract relating to the teachers' professional development at the school level:

Researcher: Aside external workshops or in-service trainings does your school organise workshops for you?

Kyei: Is like the ones we go for outside the school organised by GAST or GES. They are not usually organised.

Researcher: What about you and your colleague?

Kyei: Though we are just two, we hardly meet to discuss anything about the teaching of chemistry and our students' performance. But we meet as a department to discuss science in general.

Researcher: Why can't you and your colleague meet to review chemistry teaching and learning?

Kyei: Your guess is as good as mine.

Researcher: But you can acquire knowledge from that also?

Kyei: I will see my colleague and see if it will be possible.

The results show that there were external bodies that organise professional development (in-service training) programmes for teachers teaching science-related subjects such as chemistry. These professional development programmes were beneficial to the teacher but they hardly attended the programmes. This could be that the programmes were organised frequently but teachers failed to attend or that the programmes were not organised at all. The teachers' participation in the in-service training (professional development) programme was not continuous enough to influence the quality of their teaching (Hendriks, Luyten, Scheerens, Sleegers, & Steen, 2010) and provided the teachers no opportunity to practice what they learnt from it (Harwell, 2003). Hence, the difficulty of teachers in teaching oxidation-reduction reactions using the electron transfer model. The reform-type of professional development programmes was absent in the school. This could be attributed to the fact that teachers hardly met to share their views on the students' difficulties in chemistry and to develop the best means for assisting students. And there were no school-based programmes to provide teachers with the needed opportunities for interactions to facilitate teachers' professional development (Villegas-Reimers, 2003).

The findings from the preliminary study had shown that students had difficulties in learning oxidation-reduction reactions. The students' alternative conceptions and other conceptual difficulties stemmed from the fact that they attempted to explain any aspect of oxidation-reduction reactions using the concept of oxygen as well as hydrogen transfer even when atoms of oxygen or hydrogen were not directly involved. Students could not further identify and explain very well any aspect of oxidation-reduction using electron transfer and oxidation number models. This is because students cannot explain the direction of the transfer of electrons as well as which atom is decreasing or increasing in oxidation number; and conceptualised ionic charges of particles as oxidation numbers which only works in simple ions but not in the oxoanions.

The preliminary stage findings further show that different teachers used various instructional strategies such as lectures, questions and answers, teacher-led problem solving, group assignments, and reading assignments in teaching oxidation-reduction reactions. These instructional strategies were either teacher- or student-centered. The use of these strategies were not structured enough and the strategies lacked student active involvement in lessons; student learning from small group members; two-way communication between student and teacher; presentation of solutions in class, and appraisal of fellow student's solutions to a given problem. The poor instructional strategies could have resulted in students' alternative conceptions and other conceptual difficulties in oxidation-reduction reactions.

The instructional strategies of the teachers were dominated by teacher presentations but lack teacher supervision when it comes to group assignments out of the classroom. The strategies of the teachers could further be considered as one-sided and not selected to meet the needs of students at a particular time. That is the instructional strategies used by chemistry teachers lack the participatory approach recommended by the MOE (MOE, 2010; 2012) and hence the need for the design and development of an instructional sequence which fits the characteristics of participatory approach.

Instructional Strategy for Teaching Oxidation-Reduction Reactions

Research Question 3 sought for the design and development of alternative intervention for teaching oxidation-reduction reactions at the SHS level. The alternative intervention was PTLA. Four stages were identified and used in the PTLA. The stages were Insight stage, Interaction stage, Task stage, and Forum stage.

At the Insight stage, students' alternative conceptions were identified with respect to the aspect of oxidation-reduction reactions being learnt. Students agreed to accept or reject any alternative conceptions encountered in a lesson. The Insight stage offered students one of the most important first steps to learning chemical concepts. This is because students' alternative conceptions are difficult to change (Wenning, 2008) and hinder learning of new concepts (Sunal & Sunal, 2002). Hence, there was need to recognise students' alternative conceptions and address them.

The Interaction stage of PTLA offered students opportunity first to address alternative conceptions and to learn new concepts. It was basically student-centered and teacher-facilitated. Students actively shared ideas to accept or reject the identified alternative conceptions and to learn the new concepts. The teacher (who was the researcher) interference was minimal at this stage. The teacher came in to assist only when it was necessary (that is at the zone of proximal development of students' learning).

At the Task stage, students were guided to revise previous lessons relevant to the problem of the day. The problem of the day was solved as a process (Landcare Research, 2002) in groups. There was no interference from the teacher and students actively looked for solutions to the problem of the day.

Solutions to the problem of the day were presented by various groups at the Forum stage. Students made meaning of concepts by listening, criticising, and judging the correctness of presentations. Any dispute arose was settle by students in the presence of the teacher. Teacher at the Forum stage stressed the correctness of the concepts presented by students.

The PTLA was used in teaching try-outs at the prototype stage of the study. The prototype stage was guided by two research questions. The two research questions were Research Questions 4 and 5.

Assessing the Effectiveness of PTLA on Teaching Oxidation-Reduction Reactions

Research Question 4 sought to establish the effectiveness of PTLA on students' conceptual development of oxidation-reduction reactions at the SHS level. The results from the test instruments are presented in two sections for discussion as: students' performance and students' conceptual understanding of oxidation-reduction reactions.

Student performance on oxidation-reduction reactions

The first part of Research Question 4 sought to establish students' performance on a pre-test and posttest in oxidation-reduction reactions. This was achieved by considering students' scores in the pretest and the posttest. The results of students' percentage score of each item in the pretest and posttest are presented in Figure 4.

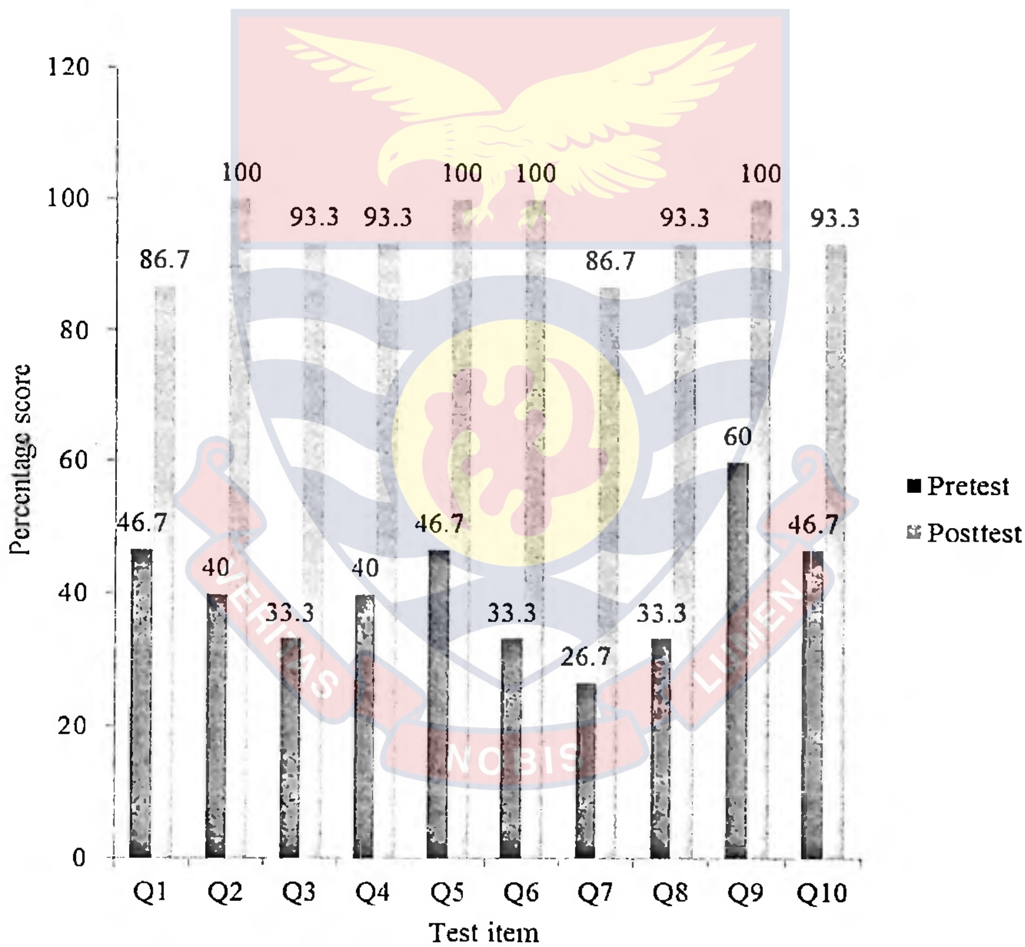

Figure 4. Bar graph of student percentage score of each item in the pretest and posttest on oxidation-reduction reactions.

The results from Figure 4 show that students failed to score full marks on all the items on oxidation-reduction reactions in the pretest. The best was Item 9 where 60.0% of the students scored the full mark, the rest of the items had less than 50.0% of the students scoring them. The students therefore had difficulty in oxidation-reduction reactions. The results from the pretest confirmed the findings from the needs and context analysis stage where the students demonstrated similar low percentage performance in oxidation-reduction reactions. However, in the posttest overwhelming majority of the students scored most of the items on oxidation-reduction reactions. In some instance, all students scored the item and the least percentage of students scoring an item in the posttest was 86.7%. This implies that teaching of oxidation-reduction reactions with PTLA helped the students to conceptualise the concept better and hence, improvement in students' percentage score in the posttest.

Students' mean scores in the pretest and the posttest were also calculated. The results of the students' mean performance are presented in Table 2. From Table 2, the mean score of the students in the pretest was 5.7 (SD = 3.8) with a minimum score of 0 and a maximum score of 11 out of the total score of 20. Two-thirds of the students scored marks ranging from 1.9 to 9.5 out of 20 marks. Students' performance in the pretest was therefore poor.

The results in Table 2 also show that the mean score of the students in the posttest was 17.1 (SD = 1.5) with a minimum of 15 marks and a maximum of 19 marks out of a total score of 20 marks. Two-thirds of students' scores ranges between 15.6 and 18.6 out of total score of 20 marks. The results clearly shows a marked improvement in students' performance. This could be attributed to students' experiences with PTLA in learning oxidation-reduction reactions which has helped them to improve on their performance.

Table 2- *Student Mean Performance in Pretest and Posttest*

Test	N	Mean	SD	Min	Max
Pretest	15	5.7	3.8	0	11
Posttest	15	17.1	1.5	15	19

Total score = 20 marks

Source: Field survey, Adu-Gyamfi (2015)

Table 3 shows that there was a statistical significant difference between the students' performance in the pretest and posttest with a mean = 17.1, SD = 1.5 compared to their performance in oxidation-reduction reactions at the beginning of teaching and learning of the concept using PTLA (mean = 5.7, SD = 3.8, $t(14) = 16.9$, $p = 0.001$). The size of the difference in the mean scores was found to be very strong (effect size = 0.976).

To further establish the relationship between students' performance in the posttest and those of the pretest, Pearson correlation coefficient was conducted and analysed. The results from the Pearson correlation coefficient show that a very strong and positive correlation was found between students' performance in the pretest on oxidation-reduction reactions and their performance in posttest on oxidation-reduction reactions (r = 0.9, p = 0.001). This is an indication that the students' performance in the pretest and posttest in the sample of students shared 81.0% of their variance in common. The findings on the students' mean performance show that there was improvement, which could be attributed to effectiveness of PTLA on student learning of oxidation-reduction reactions.

Table 3- *Results of Related Samples t-test Analysis*

Test	N	Mean	SD	t	df	p
Pretest	15	5.7	3.8	16.9	14	0.001*
Posttest	15	17.1	1.5			

* Significant, $p < 0.05$

Source: Field survey, Adu-Gyamfi (2015)

Development of students' conceptual understanding of oxidation-reduction reactions

The second part of Research Question 4 sought to establish the development of students' conceptual understanding of oxidation-reduction reactions through the eight problems of the day. Sample explanations with codes (such as G1 for a member from Group 1) are used to support the results presented.

Problem 1: Identification of oxidation-reduction reactions

In Lessons 1 and 2, students learnt the concept of oxidation and reduction processes using the PTLA. The purpose was to partly help students overcome their alternative conceptions and other conceptual difficulties in the processes of oxidation and reduction. Some of students' alternative conceptions were:

a) Oxygen is involved in all oxidation and reduction processes;

b) Substances oxidised in oxidation-reduction reactions accept electrons;

c) In redox reactions oxidation and reduction occur separately; and

d) Students had difficulties determining correct oxidation state of atoms.

To help students develop the correct conception and to overcome their alternative conceptions on identification of oxidation-reduction reactions, five groups of students with three members each were formed. The students worked in their groups throughout the two lessons, solved and presented solutions to the problem of the day (Problem 1). The following is the presentation of results from students on their conceptual understanding in Problem 1.

Students identified six chemical equations out of 10 given equations as oxidation-reduction reactions. The chemical equations were analysed using the oxidation number model. Group 1 (G1) members identified "$Fe + 2HCl \rightarrow FeCl_2 + H_2$" as oxidation-reduction reaction with the following justification:

Fe was identified as the substance increasing in oxidation number. The explanation given was: "oxidation number of Fe is 0 at the reactant side and increased to +2 at the product side"

H was identified as the substance decreasing in oxidation number. The explanation given was: "the oxidation number of H at the reactant side was +1 and decreased to 0 at the product side"

G1 members then justified the reaction, $Fe + 2HCl \rightarrow FeCl_2 + H_2$ as oxidation-reduction reaction with the explanation that: "it is redox reaction because increase in oxidation number means oxidation and decrease in oxidation number means reduction and the two occurred in the reaction"

Other student groups agreed to these explanations given to the class during the Forum stage of PTLA. The teacher, however, asked for justification why no group selected $CO_2 + H_2O \rightarrow H_2CO_3$ as oxidation-reduction reaction. The extract of the discussion was:

Teacher: Do you all accept the solution given by Group 1 on the reaction, $Fe + 2HCl \rightarrow FeCl_2 + H_2$ as correct?

Students: Yes.

Teacher: Okay; why was the reaction, "$CO_2 + H_2O \rightarrow H_2CO_3$" not selected by any group as oxidation-reduction reaction?

G2 student: because carbon is +4 in the reactant and in the product; so it is not redox.

G5 student: because the hydrogen atom is also +1 throughout; so it is not redox.

Teacher: That is good to hear.

G1 student: Okay sir; what about the addition of oxygen?

G2 student: It looks like that but the oxidation number of oxygen did not increase or decrease. It is -2 at the reactant side and the product side.

Teacher: Do we all then agree that the reaction is not redox as there is no change in oxidation number of atoms involved?

Students: Yes.

Though students identified the correct oxidation-reduction reactions among the list of given equations but there were still conceptual difficulties in the deduction of the correct oxidation state and the use oxidation number to justify the simultaneous nature of oxidation and reduction processes.

Problem 2: Half reactions

In Lessons 3 and 4, students learnt the concept of half reactions. The purpose was to partly help students overcome their alternative conceptions and other conceptual difficulties in the concept of half reactions. Some of students' alternative conceptions were:

a) Oxidising agents cause increase in charges of atoms;
b) Oxidised substances are oxidising agents;
c) A positive ion gives an indication of reduction reaction;
d) reduction half involves decrease in ionic charge of atoms;
e) Half reaction that involves removal of oxygen is reduction half;
f) Oxidation half involves oxidised ionic charge of substances;
g) Oxidation half reactions involve change of state of substances; and
h) Reduced substances decrease in ionic charge.

The five student groups with three members each in previous lessons were changed to three student groups of five members each. The students worked in their groups throughout the two lessons, solved and presented solution to the problem of the day (Problem 2). The following is the presentation of the results from students' conceptual understanding in Problem 2. Students identified oxidation half-reactions and reduction half-reactions among four given reactions.

Group presentations on identification of half reactions on "$2KBr + Cl_2 \rightarrow 2KCl + Br_2$" are presented for discussion as follows:

G3 students identified the specie oxidised and its oxidising agent as: Br^- in KBr as oxidised and Cl_2 as oxidising agent. The group explanation was: "Br^- is oxidised because the oxidation number increased from -1 to 0 and Cl_2 caused the increased in the oxidation number of Br^-".

G1 students identified the specie oxidised as KBr and the oxidising agent as Cl_2. The group explanation was: KBr is oxidised because the oxidation number of bromine atom increased and Cl_2 is the oxidising agent because its oxidation number decreased".

G2 students identified the specie reduced and its reducing agent as: Cl_2 is the substance reduced and Br^- in KBr is the reducing agent. The group explanation was: "Cl_2 is reduced because the oxidation number changed from 0 to -1 and Br^- caused the oxidation number of chlorine to reduce".

G1 students identified the oxidation half-reaction of "$2KBr + Cl_2 \rightarrow 2KCl + Br_2$" as $Br^- \rightarrow Br_2$. The explanation given was: "oxidation half is increased in oxidation number and bromine increased from -1 to 0".

G2 students identified the reduction half-reaction of "$2KBr + Cl_2 \rightarrow 2KCl + Br_2$" as $Cl_2 \rightarrow 2Cl^-$. The explanation given was: "it is the reduction half because it involves decreased in oxidation number".

After Lessons 3 and 4, it was clear that students were not comfortable with five members in a group and suggested that three members in a group would give them maximum interaction. The 60-minute period of the previous lessons was increased to 90 minutes as students felt they need extra time for interactions in the groups.

Problem 3: Balancing oxidation-reduction reaction

In Lessons 5 and 6, students learnt the concept of balancing oxidation-reduction reactions using the PTLA. The purpose was partly to help students overcome their alternative conceptions and other conceptual difficulties in the balancing of oxidation-reduction reactions. Some of students' alternative conceptions were:

a) Balancing redox reactions is like balancing any other reactions where only the atoms are balanced;
b) In balancing redox reactions H^+ and OH^- ions are added because the reactions occur respectively in acidic and basic media;
c) Half reactions involving removal of oxygen atoms are reduction; and
d) The net charge of an oxoanion is considered as the oxidation state of the central atom as it were in simple ions.

Five groups of students with three members each were once again formed. Students worked in their groups throughout the two lessons, solved and presented solution to the problem of the day (Problem 3). The following is the presentation of the results from students' conceptual understanding in Problem 3.

Students balanced a chemical equation from a given oxidation and reduction process. The components of the chemical equation were MnO_4^-/Mn^{2+} and $C_2O_4^{2-}/CO_2$. All the five groups balanced the redox equation right but Group 3's presentation was judged as the best presentation. Group 3 presented a balanced chemical equation to the problem as: "$2MnO_4^- + 5C_2O_4^{2-} + 16H^+ \rightarrow 2Mn^{2+} + 8H_2O + 10CO_2$" in the following sequence:

The unbalanced ionic equation is

$MnO_4^- + C_2O_4^{2-} \rightarrow Mn^{2+} + CO_2$

The oxidation half equation is

$C_2O_4^{2-} \rightarrow CO_2$

"Because the oxidation number of C in $C_2O_4^{2-}$ is +3 and increased to +4 in CO_2"

The reduction half equation is

$MnO_4^- \rightarrow Mn^{2+}$

"Because the oxidation number of Mn in MnO_4^- is +7 which is reduced to +2 in Mn^{2+}"

"A check of the atoms, Mn and C shows Mn atoms are balanced in the equation so we balanced C with 2 in front of CO_2 in the product side"

$C_2O_4^{2-} \rightarrow 2CO_2$

In the reduction half, "O atoms are balanced with $4H_2O$ at the product side because the reaction is in acidic medium and H atoms with $8H^+$ at the reactant side"

$MnO_4^- + 8H^+ \rightarrow Mn^{2+} + 4H_2O$

"This is not done in the oxidation half because the oxygen atoms are already balanced"

"The next is to add electrons to balance charges in the equation. The oxidation half is balanced with $2e^-$ at the product side and reduction half is balanced with $5e^-$ at the reactant side"

Oxidation half

$C_2O_4^{2-} \rightarrow 2CO_2 + 2e^-$

Reduction half

$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$

"To make the electrons in the two half equations to be equal, oxidation half is multiply through by 5 and the reduction half by 2"

Oxidation half

$5C_2O_4^{2-} \rightarrow 10CO_2 + 10e^-$

Reduction half

$2MnO_4^- + 16H^+ + 10e^- \rightarrow 2Mn^{2+} + 8H_2O$

"We then add the two half equations to have the overall equation. This helps us to cancel out the electrons to get the final equation"

$2MnO_4^- + 5C_2O_4^{2-} + 16H^+ \rightarrow 2Mn^{2+} + 8H_2O + 10CO_2$

Though the 60-minute lesson had been increased to 90-minute lesson in Lessons 5 and 6 students needed more time at the Insight stage where students' alternative conceptions were identified and addressed. The time spent at the Insight stage increased from 10 minutes to 20 minutes. This is because students thought that when their alternative conceptions were identified and addressed they make meaning of the new concept better.

Problem 4: Everyday application of oxidation-reduction reactions

In Lessons 7 and 8, students applied the concept of oxidation and reduction processes in everyday life using PTLA for 90 minutes. The purpose was to help students overcome their alternative conceptions and other conceptual difficulties in application of the processes of oxidation and reduction in everyday life. Some of students' alternative conceptions were:

a) Brownish colour on iron metal is formed by addition of hydrogen;

b) Heating in combustion adds oxygen atoms;

c) Carbon as a catalyst reduces iron oxide by removal of oxygen atoms; and

d) Students had difficulties in conceptualising the role of atmospheric oxygen in rusting; and

e) Students had conceptual difficulties using electron transfer or oxidation number in everyday use of oxidation and reduction processes.

Five groups of students with three members each were maintained. The students worked in their groups throughout the two lessons, solved and presented solution to the problem of the day (Problem 4). The following is the presentation of the results from students' conceptual understanding on Problem 4.

Students used the concept of oxidation and reduction processes acquired in previous lessons in an everyday life application of oxidation-reduction reactions. The problem of the day was about fuel cell which used a mixture of hydrogen and oxygen in alkaline solution as fuel to generate electricity. The two equations from the reaction in the fuel cell were given as:

$O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$

$2H_2(g) + 4OH^-(aq) \rightarrow 4H_2O(l) + 4e^-$

The groups of students analysed the two chemical equations as:

G4 identified the oxidation half process as:

$2H_2(g) + 4OH^-(aq) \rightarrow 4H_2O(l) + 4e^-$

"Because hydrogen atom in H_2 has oxidation number of 0 at the reactant side and this increased to +1 in H_2O at the product side"

G1 identified the reduction half process as:

$O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$

"Because the oxidation number of O decreased from 0 in O_2 to -2 in OH^-"

G5 wrote the overall equation of oxidation and reduction processes as

$2H_2(g) + 4OH^-(aq) \rightarrow 4H_2O(l) + 4e^-$

$O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$

$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$

"To obtain the overall equation, the $4e^-$ and $4OH^-$ species at both sides of the equation will cancel out and $2H_2O$ at the reactant side will cancel 2 out of $4H_2O$ at the product side to give $2H_2O$"

G5 explained how the fuel cell generates electricity as: "the hydrogen atom in H_2 release electrons to increase in oxidation number as H^+. Oxygen atom in O_2 will accept electrons to decrease in oxidation number as O^{2-}. So we think this movement of electrons will go on and on to generate electricity"

G4 explained how the fuel cell generates electricity as: "Is like the dry cell, electrons will be released by H at one pole and it will be accepted by O at another pole. It will be a continuous processes of oxidation and reduction to generate electricity"

The findings from the four problems of the day show that students demonstrated promising conceptual understanding of oxidation-reduction reactions. This is because students' explanations of solutions to each problem using the concept of oxidation and reduction processes were correct. This could be attributed to the effectiveness of PTLA on student learning of oxidation-reduction reactions. The promising conceptual understanding on oxidation-reduction reactions demonstrated by students could be because the problems of the day were solved in groups and that students may not be able to demonstrate such conception individually. There was therefore the need to compare students' conceptual understanding on oxidation-reduction reactions in the posttest to the pretest to finally ascertain the effectiveness of PTLA on student learning of the concept.

Students' conceptual understanding in the pretest and posttest

The last part of Research Question 4 sought to further establish development of students' conceptual understanding of oxidation-reduction reactions as a consequence of PTLA on student learning of the concept. The results are presented in line with identification of oxidation-reduction reaction, oxidised specie, reduced specie, oxidising agent, reducing agent, oxidation half-reaction, reduction half-reaction, and spectator ion. Sample explanations and codes (such as 'PR001' for student 1 in the pretest and 'PO001' for student 1 in the posttest) are used to support the presentations.

Identification of oxidation-reduction reaction: Item 1 on the pretest and Item 4 on the posttest sought to find out students' conceptual understanding on identifying whether a reaction is oxidation-reduction reaction. The results are grouped as:

Alternative conceptions: in oxidation-reduction reactions, oxidised species accept electrons. An excerpt is: "Zn^{2+} has been oxidised by gain of electrons to form Zn" (PR011). The chemistry seemed inaccurate, however, in the posttest, students conceptualised that the reaction was oxidation-reduction reaction because it involves change in oxidation number. The excerpt is: "the answer is $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$; because the oxidation number of Zn is 0 and Cu is +2 at the reactant side but in the product Zn is +2 and Cu is 0" (PO011).

Oxidation-reduction reactions involve copper (Cu) atom. An excerpt is: "$Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$; because the presence of the Cu makes the equation redox from the others" (PR005). In the posttest however, students conceptualised that the reaction is oxidation-reduction reaction because there is oxidation and reduction. The excerpt is: "the answer is $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$; because there are both oxidation half and reduction half reactions" (PO005).

Oxidation-reduction reactions contain acids and bases. An excerpt is: "$MgO + 2HCl \rightarrow MgCl_2 + H_2O$; because it contains an acid and a base compounds in it reactant. Therefore HCl oxidised the equation. It breaks down to combine with Mg and H_2O is also formed" (PR002). In the posttest, student conceptualised oxidation-reduction reactions as involving oxidation; which is increased in oxidation number and reduction; which is decreased in oxidation number. The excerpt is: "$Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$; because Zn has increased in oxidation number and Cu has also decreased in oxidation number" (PO002).

Oxidation-reduction reactions undergo chemical equation. An excerpt is: "$MgO + 2HCl \rightarrow MgCl_2 + H_2O$; because it undergoes chemical equation" (PR010). In the posttest however, students conceptualised the correct oxidation-reduction reaction as involving increase in oxidation state of one atom and a decrease in oxidation state of another atom. The excerpt is: "$Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$ is redox reaction because the oxidation number of Zn changed from 0 to +2 and Cu changed from +2 to 0 (PO010).

Other conceptual difficulties: students had conceptual difficulties in identifying oxidation-reduction reactions using electron transfer in the pretest. An excerpt is: "$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3$; this is because there is loss and gain of electrons in the reactions" (PR004). In the posttest, students conceptualised the correct oxidation-reduction reaction as involving oxidation (increased in oxidation number) and reduction (decreased in oxidation number). The excerpt is: "$Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$; it is a redox reaction because there is an increased in oxidation number of Zn and decrease in oxidation number of Cu" (PO004).

Students had difficulties in using species reduced or oxidised to conceptualise oxidation-reduction reactions. An excerpt is: "in the $Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3$, Ca^{2+} has been reduced and CO_3^{2-} has been oxidised hence the reaction is redox" (PR013). In the posttest however, students conceptualised the correct oxidation-reduction reaction as involving oxidation (increased in oxidation number) and reduction (decreased in oxidation number). The excerpt is: "$Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$; it is a redox reaction because oxidation involves increase in oxidation number (Zn) and reduction involves decrease in oxidation number (Cu)" (PO013).

Oxidised specie: On the pretest and posttest Item 2 sought to find out students' conceptual understanding of oxidised species in oxidation-reduction reactions using $2Br^- + Sn^{2+} \rightarrow Br_2 + Sn$. The results are grouped as:

Alternative conceptions: oxidised species accept electrons. An excerpt is: "Br^- because it has gained an electron" (PR003). In the posttest, students conceptualised oxidised species as atoms (substances) with increased oxidation state. The excerpt is: "Br^- has increased in oxidation number from -1 to 0" (PO003).

Oxidised species increase in ionic charges. An excerpt is: "Br^- there is an increase in charge from $2Br^-$ to Br_2" (PR007). In the posttest however, students conceptualised oxidised substances as atoms (substances) with increase in oxidation state. The excerpt is: "Br^- because it increased in oxidation number" (PO007).

Oxidised species change from ionic to atomic state. An excerpt is: "because the Sn^{2+} changes to Sn as a result from ionic state to its atomic state" (PR002). In the posttest, students conceptualised correctly oxidised species as those that increase in oxidation state. The excerpt is: "Br^- has increased from -1 to 0 in oxidation number" (PO002).

Other conceptual difficulties: students had difficulties in conceptualising oxidised species using electron transfer. An excerpt is: "Sn^{2+}; loss electrons to become stable" (PR008). In the posttest, students conceptualised oxidised species as atoms (substances) increased in oxidation state. The excerpt is: "Br^-; it is oxidised because there is a gain in oxidation number from negative to zero" (PO008).

Students had difficulties in conceptualising oxidised species using oxidation number. An excerpt is: "because Br_2 has increased its oxidation number from -2 to 0" (PR001). In the posttest, students conceptualised correctly oxidised substances as those with increase in oxidation state. The excerpt is: "Br^-; this is due to the increase in oxidation number from -1 to 0 (ie, from Br^- to Br_2)" (PO001).

Reduced specie: Item 3 on the pretest and Item 8 on the posttest sought to find out students' conceptual understanding of species reduced in the reaction, $2Br^- + Sn^{2+} \rightarrow Br_2 + Sn$. The results are grouped as:

Alternative conceptions: reduced species donate electrons. An excerpt is: "Sn^{2+}; because it has loss an electron" (PR003). In the posttest however, students conceptualised that reduced species decrease in oxidation state. The excerpt is: "Sn^{2+} has decreased in oxidation number from +2 to 0" (PO003).

Reduced substances give out their charges. An excerpt is: "Sn^{2+}; because it carries out electrons which loss some charge" (PR010). In the posttest however, students conceptualised that reduced species decrease in oxidation state. The excerpt is: "Sn^{2+}; because the oxidation number reduced or changed from +2 to 0" (PO010).

Reduced species decrease in the ionic charge. An excerpt is: "Sn^{2+}; because the charge on Sn^{2+} has been reduced from +2 to +1" (PR013). In the posttest however, students conceptualised that reduced species decreased in oxidation state. The excerpt is: "Sn^{2+}; because there is decrease in oxidation number from +2 to 0" (PO013).

Reduced species change from pure state to molecular form. An excerpt is: "Br^-; because it changes from its pure state to form a molecule" (PR002). In the posttest however, students conceptualised that reduced species decrease in oxidation state. The excerpt is: "Sn^{2+}; has reduced in oxidation number from +2 to 0 in the reaction" (PO002).

Reduced species donate electrons. An excerpt is: "Br^-; because it changes from -1 by loss of electron to 0" (PR011). In the posttest however, students conceptualised correctly that reduced species decrease in oxidation state. The excerpt is: "the substance reduced is Sn^{2+} because the oxidation number of Sn reduced from +2 to 0" (PO011).

Members of Group 7 elements reduce in reactions. An excerpt is: "Br_2; this is because all halogens (Group 7 elements) are reducing substances" (PR008). In the posttest, students conceptualised correctly that reduced species decrease in oxidation state. The excerpt is: "the answer is Sn^{2+} because there is decreased in its oxidation number from +2 to 0" (PO008).

Other conceptual difficulties: students had difficulties in conceptualising reduced species using electron transfer. An excerpt is: "Br_2; because reduction occurs in both sides because the electrons were removed from $2Br^-$" (PR006). In the posttest, students conceptualised correctly that reduced species decrease in oxidation state. The excerpt is: "Sn^{2+}; because there is decrease in oxidation number from +2 to 0" (PO006)

One of the students failed to conceptualise the reduced specie in the pretest but in the posttest he/she conceptualised that reduced species decrease in oxidation state. The explanation given was: "the reduced substance is Sn^{2+}. This is because in the reactant the oxidation number of Sn is +2 and in the product side the oxidation number is 0 and this shows Sn has reduced in the reaction" (PO015).

Oxidising agent: Item 4 on the pretest and Item 3 on the posttest sought to find out students' conceptual understanding of oxidising agents in oxidation-reduction reactions such as $Ag + Ni^{2+} \rightarrow Ag^{+} + Ni$. The results are grouped as:

Alternative conceptions: oxidising agents reduce in net ionic charge. An excerpt is: "Ni^{2+}; because its net charge has been reduced from Ni^{2+} to Ni" (PR003). In the posttest however, students conceptualised oxidising agent as species that cause another specie to increase in oxidation state. The excerpt is: "Ni^{2+} has caused Ag to increase in oxidation number from 0 to +1" (PO003).

Oxidising agents are species oxidised in reactions. An excerpt is: "Ag because the number in the reaction has been oxidized or increased in the reaction" (PR009). In the posttest however, students conceptualised that oxidising agents are species that cause oxidation of another specie. The excerpt is: "because Ni^{2+} caused Ag to be oxidised" (PO009).

Oxidising agents possess (positive) charge. An excerpt is: "Ag^+ because it carries out positive charge" (PR010). In the posttest however, students conceptualised that oxidising agents decrease in oxidation state. The excerpt is: "Ni^{2+} is the oxidising agent because the oxidation number reduced from +2 to 0" (PO010).

Oxidising agents cause increase in charges of other species. An excerpt is: "Ni^{2+} causes the Ag to increase in charge thus, oxidised. That is Ni^{2+} is reduced so it is the oxidising agent" (PR007). In the posttest however, students conceptualised that oxidising agents cause the increase in oxidation state of another specie. The excerpt is: "Ni^{2+}; because it caused the oxidation number of Ag to increase from 0 to +1" (PO007).

Oxidising agents change from atomic state to ionic state. An excerpt is: "Ag; because it changes from atomic state to form an ion" (PR002). In the posttest however, students conceptualised that oxidising agents cause increase in oxidation state of another specie in reactions. The excerpt is: "Ni^{2+} has caused Ag to increase in oxidation number" (PO002).

Other conceptual difficulties: students had difficulties in conceptualising oxidising agents using electron transfer. An excerpt is: "Ag is the oxidizing agent because electrons are added" (PR006). In the posttest however, students conceptualised that oxidising agents are substances that cause the oxidation of another substance. The excerpt is: "Ni^{2+}; because it has caused Ag to be oxidised" (PO006).

Students had difficulties in conceptualising oxidising agents using oxidation number. An excerpt is: “Ag is the oxidising agent because the oxidation of the reactant side is +1 and at the reaction is 0” (PR014). In the posttest however, students conceptualised oxidising agents are species (atoms) that cause increase in oxidation state of another specie in chemical reactions. The excerpt is: “an oxidising agent is a substance which causes an increase in oxidation number of the substance; hence the answer is Ni^{2+}” (PO014).

Students had conceptual difficulties in conceptualising oxidising agents using species reduced or oxidised in reactions. The excerpts were: “because Ag has undergone reduction” (PR001); and “because Ag^{+} caused Ni^{2+} to be oxidised” (PR015). In the posttest however, the students conceptualised that oxidising agents cause increase in oxidation number of another substance in chemical reactions. The excerpts are: “Ni^{2+}; because it has caused the increased in oxidation number of Ag from 0 to +1” (PO001); “in the reactant side Ni caused Ag to increase from 0 to +1 in the product side and oxidation agents cause increase in oxidation number of other substances” (PO015).

Reducing agents: Item 5 on both the pretest and posttest sought to find out students’ conceptual understanding of reducing agents in oxidation-reduction reactions such as $Ag + Ni^{2+} \rightarrow Ag^{+} + Ni$. The results are grouped as:

Alternative conceptions: reducing agents have net ionic charge oxidised. An excerpt is: “Ag; because its net charge has been oxidized from Ag to Ag^{+}” (PR003). In the posttest however, students conceptualised that reducing agents cause decrease in oxidation state of other species. The excerpt is: “Ag has caused Ni^{2+} to decrease in oxidation number from +2 to 0” (PO003).

Reducing agents are species reduced in reactions. An excerpt is: “Ni^{2+} is reducing agent because it reduced to Ni” (PR006). In the posttest however, the students conceptualised that reducing agents cause decrease in oxidation state of another specie. The excerpt is: “because Ag has caused a decreased in oxidation number of Ni^{2+}” (PO006).

Reducing agents are species that change from ionic state to atomic state. An excerpt is: “Ni^{2+}; because it changes from ionic state to its atomic state” (PR002). In the posttest however, students conceptualised that reducing agents cause decrease in oxidation state of other substances. The excerpt is: “Ag has caused Ni^{2+} to decrease in oxidation number” (PO002).

Reducing agents oxidise ionic charges of other substances in reactions. An excerpt is: “Ni^{2+}; because it has the oxidised charge of 2 and that makes it reduced in the reaction” (PR010). In the posttest however, students conceptualised that reducing agents increase in oxidation state or cause decrease in oxidation state of another substance in chemical reactions. The excerpt was: “Ag is the reducing agent because the oxidation number increased from 0 to +1” (PO010).

Reducing agents are species that have reduced in number in chemical reactions. An excerpt is: “Ni^{2+}; because the number in the reaction has been reduced” (PR009). In the posttest however, students conceptualised that reducing agents are species that cause decrease in oxidation number of other species in chemical reactions. The excerpt is: "Ag; because it caused Ni^{2+} to reduce from oxidation state of +2 to 0" (PO009).

Other conceptual difficulties: students had difficulties in conceptualising reducing agents using electron transfer. An excerpt is: "Ni^{2+}; because Ni^{2+} has lost 2 electrons and it has undergone oxidation" (PR001). In the posttest however, students conceptualised reducing agents as species causing decrease in oxidation state of another substance. The excerpt is: "Ag is a reducing agent because it caused the decreased in oxidation number of Ni^{2+}" (PO001).

Reduction half-reactions: Items 6 and 8 on the pretest and Items 7 and 9 on the posttest sought to find out students' conceptual understanding of reduction half-reactions in $ClO_3^- + Cl^- \rightarrow Cl_2 + ClO_2$ and $2HCl + Zn \rightarrow ZnCl_2 + H_2$. The results are grouped as:

Alternative conceptions: reduction half-reaction involves decrease in ionic charge of the species in chemical reactions. An excerpt is: "$2H^+$ is reduced to H_2 that is decrease in positive charge" (PR007). In the posttest however, students explained that reduction half involves decrease in oxidation state. The excerpt is: "because H^+ decreased in oxidation number from +1 to 0" (PO007).

Reduction half-reactions involve change of state of species. The excerpts are: "$Cl^- \rightarrow Cl_2$; because it changes from ionic state to a gaseous state" (PR002); and "$Zn \rightarrow Zn^{2+}$ because Zn is reduced from its atomic state to form an ion" (PR008). In the posttest however, students conceptualised that reduction half-reactions involve decrease in oxidation state of species involved. The excerpts are: "$ClO_3^- \rightarrow ClO_2$ is the reducing half because Cl_2 has reduced in oxidation number" (PO002); and "its oxidation number is reduced from +1 to 0. That means it has reduced its oxidation number" (PO008).

Reduction half-reactions involve decrease in the number of certain atom. An excerpt is: "Cl^- → Cl_2; because the number of chlorine in the reaction has been reduced" (PR009). In the posttest however, students conceptualised that reduction half involves decrease in oxidation state of atoms involved. The excerpt is: "ClO_3^- reduces in oxidation number" (PO009).

Reduction half-reactions involve loss of electrons. The excerpts are: "because Cl^- loses the extra electron to become Cl_2" (PR011); and "Zn → Zn^{2+} this is because Zn has loss electron" (PR004). In the posttest however, students conceptualised that reduction half-reactions involve decrease in oxidation state. The excerpts are: "the reduction half is ClO_3^- → ClO_2 because Cl changed from +5 to +4" (PO011); and "this is reduction half reaction because there is a decreased in oxidation number of H^+ → H_2 ie +1 to 0" (PO004).

Other conceptual difficulties: students had difficulties in conceptualising reduction half-reactions using transfer of oxygen atoms. An excerpt is: "ClO_3^- →ClO_2; this is because it has lost oxygen molecules in the cause of the reaction" (PR004). In the posttest however, students conceptualised that reduction half-reactions involve decrease in oxidation state of atoms involved. The excerpt is: "ClO_3^- → ClO_2 is a reduction half reaction because there is a decreased in oxidation number of ClO_3^- to ClO_2" (PO004).

In the pretest, students had difficulties in conceptualising the reduction half-reactions of ClO_3^- + Cl^- → Cl_2 + ClO_2 and 2HCl + Zn → $ZnCl_2$ +

H_2. However, in the posttest students conceptualised $ClO_3^- \rightarrow ClO_2$ and $2H^+ \rightarrow H_2$ as the reduction half-reactions and explained reduction half reactions involve decrease in oxidation state. The excerpts are: "because Cl in ClO_3^- has decreased in oxidation number from +5 to +4 in ClO_2" (PO005); and "Cl in ClO_3^- has decreased in oxidation number from +5 to +4 in ClO_2 and reduction half is a decrease in oxidation number" (PO014). The rest are: "because $2H^+$ has reduced from oxidation number of +1 to 0" (PO009); and "$2H^+ \rightarrow H_2$ is the reduction half because H reduced from +2 to 0" (PO010).

Oxidation half reactions: Items 7 and 9 on the pretest and Items 6 and 10 on the posttest sought to find out students' conceptual understanding of oxidation half-reactions in $ClO_3^- + Cl^- \rightarrow Cl_2 + ClO_2$ and $2HCl + Zn \rightarrow ZnCl_2 + H_2$. The results are grouped as:

Alternative conceptions: oxidation half-reactions involve gain of electrons. The excerpts are: "because the Cl has gain electrons to become Cl_2" (PR006); and "Zn^{2+} gains an electron to become equal with Zn" (PR011). In the posttest, students conceptualised that oxidation half-reactions involve increase in oxidation state. The excerpts are: "because chlorine has increased from -1 to 0 (PO006); and "the oxidation half is $Zn \rightarrow Zn^{2+}$ because oxidation number of Zn in reactant is 0 and in product is +2. Increase in oxidation number is oxidation half" (PO011).

Oxidation half-reactions involve oxidised ionic charge of substances in chemical reactions. The excerpts are: "Zn is being oxidized to have charge of +2 (PR007); and "the charge on Zn has been oxidized to give Zn^{2+} and due to increase in charge of Zn^{2+}" (PR013). In the posttest however, students conceptualised that oxidation half reactions involve increase in oxidation state. The excerpt is: "Zn increased in oxidation number from 0 to +2" (PO007).

Oxidation half-reactions involve change of state of substances. An excerpt is: "ClO_3^- → ClO_2; because it changes from ionic state to a compound" (PR002). In the posttest however, students conceptualised that oxidation half-reactions involve increase in oxidation state of atoms involved. The excerpt is: "Cl- → Cl_2 is the oxidation half because Cl^- has increased in oxidation number to form Cl_2" (PO002).

Oxidation half-reactions involve gain of electrons. An excerpt is: "ClO_3^- gained electron to become ClO_2" (PR008). In the posttest however, students explained oxidation half-reactions involve increase in oxidation state. The excerpt is: "Cl^- → Cl_2; it has increased its oxidation number from -1 to 0 (PO008).

Oxidation half-reactions involve breakdown of acidic substances. An excerpt is: "$2H^+$ → H_2 because the $2H^+$ which is an acidic ion breaks down to form H_2 which is a gas" (PR002). In the posttest however, students conceptualised that oxidation half-reactions involve increase in oxidation state. The excerpt is: "Zn → Zn^{2+} is the oxidation half because Zn has increased in oxidation number to form Zn^{2+}" (PO002).

Oxidation half-reactions involve complete reaction of substances. An excerpt is: "$2H^+$ → H_2 this is because H^+ reacted completely to form H_2" (PR004). In the posttest however, students conceptualised that oxidation half-reactions involve increase in oxidation state. The excerpt is: "this is the answer because there is an increased in oxidation number of Zn from 0 to +2" (PO004).

Oxidation half-reactions involve substances reacting to become stable. An excerpt is: "the H^+ is gaining to become H_2 in the reaction. It is done to become stable in the equation" (PR012). In the posttest however, students conceptualised oxidation half-reactions as involving increase in oxidation state. The excerpt is: "$Zn \rightarrow Zn^{2+}$ is the oxidation half because Zn has increased in oxidation number to form Zn^{2+}" (PO0012).

Other conceptual difficulties: students had difficulties in conceptualising any of the half reactions of $ClO_3^- + Cl^- \rightarrow Cl_2 + ClO_2$ as oxidation half-reactions but claimed both half reactions are reduction half-reactions. An excerpt is: "all the reaction is not oxidation half but rather reduction half reaction" (PR014). In the posttest however, students conceptualised that oxidation half-reactions involve increase in oxidation state. The excerpt is: "oxidation half reaction is the increase in oxidation number. Cl^- has increased from -1 to 0 in Cl_2" (PO014).

Students had difficulties in conceptualising any oxidation half-reactions of $ClO_3^- + Cl^- \rightarrow Cl_2 + ClO_2$ and $2HCl + Zn \rightarrow ZnCl_2 + H_2$ in the pretest. In the posttest however, students conceptualised oxidation half-reactions as involving increase in oxidation state. The excerpts are: "the oxidation half is $Cl^- \rightarrow Cl_2$ because oxidation increased from -1 to 0" (PO011); and "this is the answer because chlorine in the reactant side is -1 and increased to 0 in the product side and this is oxidation as oxidation involves increase in oxidation number"

(PO015). The rest are: "because Zn has been oxidised from oxidation state of 0 to +2" (PO009); and "oxidation half reaction increases in oxidation number and Zn has increased from 0 to +2" (PO014).

Spectator ions: Item 10 on the pretest and Item 1 on the posttest sought to find out students' conceptual understanding of spectator ion in chemical reactions such as $2HCl + Zn \rightarrow ZnCl_2 + H_2$. The results are grouped as:

Alternative conceptions: spectator ions are species that help to balance other atoms. An excerpt is: "it is helping the zinc to be balanced in the reaction" (PR012). In the posttest however, students conceptualised that spectator ions as ions with no change in oxidation state throughout chemical reactions. The excerpt is: "the spectator ion is Cl^- because the oxidation number is the same" (PO012).

Spectator ions have the same ionic charge throughout the reaction. An excerpt is: "the charge of Cl^- remains the same throughout the reaction" (PR015). In the posttest however, students conceptualised that spectator ions do not have their oxidation state change throughout the chemical reactions. The excerpt is: "Cl^- has -1 at the reactant side and -1 at the product side and this means the same oxidation number in the reaction" (PO015).

Spectator ions are introduced to complete chemical reactions. An excerpt is: "Zn^{2+}; because it was introduced in order to complete the reaction" (PR013). In the posttest however, students conceptualised that spectator ions do not take part in chemical reactions. The explanation was: "Cl^-; because it does not take part in the oxidation and reduction" (PO013).

Other conceptual difficulties: In the pretest, students had difficulties in conceptualising spectator ions as species with no net effect in the chemical reactions. The excerpts are: "$2H^+$; because 2HCl is an acid, the $2H^+$ act as the oxidising agent" (PR002); and "the spectator ion is $2H^+$ because the reaction formed to give the $ZnCl_2$ to H_2. So therefore H_2 is the spectator ion" (PR005). In the posttest, students conceptualised that spectator ions are ions that have the same oxidation state throughout chemical reactions. The excerpts are: "Cl^- is the answer because it has the same oxidation number" (PO002); and "Cl^- is the spectator ion as the oxidation number of Cl remained the same" (PO005).

Some of the students failed to identify any of the ions as spectator ions in the pretest. However, in the posttest students identified Cl^- as the spectator ion in the reaction and explained that spectator ions do not take part in chemical reactions as they have constant oxidation state. The excerpts are: "it is the ion which did not take part in the reaction, ie. having the constant oxidation number" (PO010); and "because it does not take part in the reaction because the oxidation number remains constant" (PO006).

The findings show that students' conceptual understanding of oxidation-reduction reactions improved in the posttest. This could be attributed to students' learning of oxidation-reduction reactions using PTLA, which exposed them to conceptual problems, gave them opportunity to solve problems on their own, and helped them to identify and understand their mistakes (Felder, 1993). This is because not only was the PTLA helping individual students to perform on the test items in oxidation-reduction reactions but they were able to justify correctly, the chemistry behind concepts under oxidation-reduction reactions. Hence, the new teaching approach is effective in developing students' conceptual understanding of oxidation-reduction reactions.

Students' Views on the use of PTLA as an Instructional Strategy in Learning Oxidation-Reduction Reactions

Research Question 5 sought to find out the views of students on learning oxidation-reduction reactions using the PTLA. The results are presented in themes as:

a) learner satisfaction (describes how satisfied students are in development of conceptual understanding on the concept at the end of instruction);
b) participatory nature (describes the involvement of students in lessons);
c) teacher role (describes the involvement of teacher in lessons); and
d) areas for improvement (describe areas of the PTLA that students recommended should be given some consideration).

Learner satisfaction

At the end of every lesson, students expressed their views as to whether the lesson was a success or not. This showed how satisfied students were at the end of each lesson. The learner satisfaction was linked to student development of conceptual understanding of oxidation-reduction reactions in that lesson. Students generally expressed satisfaction at the end of the lessons meaning they had developed the concept. An extract from one of the students was:

Teacher: Is today's lesson successful?

Kwadwo: Yes.

Teacher: Explain why you consider it a success.

Kwadwo: I understand the topic very well.

Teacher: Sure?

Kwadwo: Oh yes; because I can use the idea I have today in solving questions and also in explaining myself.

Not only were students satisfied in terms of their understanding in the lessons but there was a general expression that the approach to teaching and learning had eased the difficulty with which students had learnt oxidation-reduction reactions in a previous lesson. An extract from Akua was:

Teacher: Any other reason why the lesson was a success.

Akua: To me the lesson is a success because it is easy for me.

Teacher: Can you explain further?

Akua: The first time we learnt this topic it was very difficult for me.

Teacher: How difficult?

Akua: I did not know the oxidation, the reduction and more so reducing and oxidising agents but now I can easily see them.

Teacher: Sure?

Akua: Oh yes.

Almost half of the students linked their satisfaction of the lessons to their interest in the lessons. They indicated that the ease with which they learnt the concept of oxidation-reduction reactions with the new approach to teaching and learning made learning interesting. An extract from Obaa was:

Teacher: Is today's lesson successful?

Obaa: Yes.

Teacher: Explain why you consider it a success.

Obaa: It is because it is getting interested.

Teacher: ... but how could that be considered as a success?

Obaa: You see whenever they teach and you don't understand you are not happy and the way you are teaching us I understand and that makes me happy.

The results show that the use of PTLA in teaching and learning of oxidation-reduction reactions assured learner satisfaction at the end of the teaching and learning session. This satisfaction could have been achieved through contributions from each student in groups. The extent of satisfaction could be measured with student development of conceptual understanding, student ability to overcome learning difficulties, and student attitudinal change. This is because if students are able to explain the chemistry behind chemical concepts, it is a demonstration of conceptual understanding (Cheun et al., 2008) and hence, student satisfaction in the lesson. Students therefore appreciated that a successful lesson is one where there is satisfaction in terms of conceptual understanding in learning chemical concepts and students saw this through the use of the PTLA.

Attitude is an important factor in learning of science in general and chemistry in particular. It is therefore not out of place to link learner satisfaction of a lesson to attitudinal change. Students appreciated that PTLA assures attitudinal change; helping them to develop interest in learning chemical concepts.

Participatory nature

The new teaching approach was designed with the intent of making it participatory for students. Hence, the involvement of students at each stage of the PTLA was important. In general, students described the lessons as very interactive. Ayamba described the lessons as interactive with respect to student involvement with the following words: "we did everything on our own to develop our own understanding of what you're teaching us. This is not usually seen in our classes".

The group interaction was also linked to the interactive nature of the PTLA. Students' view was that the group interactions offered them opportunity to share ideas on oxidation-reduction reactions. The small number of students in each group (three members) offered them more room to share ideas very well. An extract from Kpai illustrates this:

Teacher: Was the lesson participatory enough for you?

Kpai: Yes.

Teacher: In one word, describe how participatory the lesson was.

Kpai: Interactive.

Teacher: Good but can you explain further.

Kpai: The working in groups gave us the chance to interact. So we interacted to share ideas and agree on points before we write it down.

Teacher: Was the number of group members okay for interacting?

Kpai: I think so because it gave us more room to share our ideas.

Teacher: Should the number in the groups be increased next time?

Kpai: well it can be increased to four or five

Teacher: Why?

Kpai: More than five will make it ineffective for you to consider everyone's view.

The Forum stage of the PTLA was also described as interactive. This is because students actively presented, challenged, and accepted solutions of their peers. Adu explained that "we interacted by sharing ideas during the presentation of solutions. That is this person will say this and another person will say that and by that we're learning".

Evaluating colleagues' solutions to the problem of the day on oxidation-reduction reactions as correct or incorrect was identified as an unusual challenge in the 'normal' classroom of students' learning. It made students active and boosted their confidence level in the lessons. In the first week, students were not comfortable seeing their colleagues criticising their presentations publicly. Bengre explained that:

> We are used to our teachers marking our work and presenting the correct solution for us to make comparisons and do corrections. We are not used to taking the place of our teachers in teaching and challenging our friends in class… and here we're doing all that. It is not easy.

The PTLA built students' confidence in learning oxidation-reduction reactions. This was seen after the first week when presentations and criticisms became part of students' learning. An extract from Kessewaa illustrates this.

Teacher: You seem comfortable now presenting and explaining your solution to the class?

Kessewaa: Yes.

Teacher: Why?

Kessewaa: Is about what we have experienced so far in learning redox with you.

Teacher: Is the practice cool for you?

Kessewaa: Oh yes; as it gives us confidence and helps us to prepare well for another time… and if I prepare well I'm okay with all comments from my friend.

Generally, students appreciated that there were moments of reflection in learning oxidation-reduction reactions using the PTLA. This was linked to the period where students constructively criticised the presentation of their colleague students' solutions. Students considered the criticisms from colleagues in previous lessons as they searched for solution to a new problem of the day. This helped the groups to search for the most appropriate solutions in order to get it correct during presentations. Serwaa explained that: "the criticisms from other group members make our group wants to get work right during the next presentation because as we work we think of what our friends saw wrong with ours and improve on it".

The results show that indeed the PTLA was participatory by nature. This is because students appreciated that the PTLA was interactive, student-centered, evaluative, and reflective. A participatory instruction should place student at the center of teaching and learning activities (Shen et al., 2004) where students interact with colleague students and teacher. Students interact actively (McLoughlin & Lee, 2007) through sharing of ideas which developed in students the interest in learning. Using the PTLA in teaching oxidation-reduction reactions made students the main focus of learning with little support from the teacher. This active students' involvement in groups could have contributed to students' conceptual understanding (Felder, 1993; Peterson, 2006) of oxidation-reduction reactions. Students had opportunities of evaluating (Pain et al., 2011) their own works using the PTLA, which built their confidence in learning chemical concepts. During students' evaluation, students argued on concepts and ideas trying to convince themselves and colleagues the correctness or otherwise of a presentation of idea or concept. Another attribute of participatory instruction was reflection (Pain et al., 2011; Trauth-Nare & Buck, 2011). In teaching oxidation-reduction reactions using the PTLA, students reflected on each day's lessons and most especially during the task stage where they were looking for a solution to the day's problem.

Teacher's role

The role of teachers in most chemistry lessons is said to be that of dominant type where teachers present information to students with little or no student involvement. However, in lessons where the PTLA was used in teaching and learning of oxidation-reduction reactions, students described teacher involvement as not being that of teacher-dominance type but that where the teacher stayed at the background and giving students more room to interact. Kwarteng made this observation about the role of the teacher: "you stayed at the background as we learnt and you didn't interfere with our learning as seen in our 'normal' classes".

There were instances where students' discussions on concepts in the groups were not accurate but the teacher only listened as students tried to conceptualise the aspect of oxidation-reduction reactions being learnt. Antwi had this to say about the role of the teacher:

> You allowed us to learn on our own with little support by asking us some questions. At times we may be wrong but you allow us to get it right on our own. You only came in when all of us can't get it right.

Students appreciated that it was normal for teachers to interfere with any presentation they made in their 'normal' classrooms. That is whenever a student got a solution to a question wrong, teachers popped up to take control of the presentation. However, in using the PTLA and in particular at the Forum stage, students presented solutions with no interference from the teacher. Serwaa made the following observation of the role of teacher:

> The way you're teaching us is different. You don't disturb us even if we are wrong. You allow us to present our answers and my friends will tell whether the answer is right or wrong and you will only listen and ask questions. You come in when we have all finish and selected the best answer.

The results show once again that the PTLA promoted participatory instruction. This is because students appreciated that learning was centered on them with the teacher having minimal control over their learning. In that case the role of teacher could be described as facilitating (Pain et al., 2011). The teacher did not dominate when using the PTLA in teaching. This could have contributed to student reflection since facilitated learning engages students in reflective thinking (Herod, 2012). In constructivist instruction, the teacher provides support (Kruse, 2009) at the zone of proximal development, and in using the PTLA the teacher came in only when it was necessary to provide support for student learning of chemical concepts.

Areas for improvement and suggestions from students

Students recommended some areas of the use of the PTLA in teaching and learning of oxidation-reduction reactions that needed consideration for improvement in the quality of the intervention. The time period for the lessons on oxidation-reduction reactions with the PTLA was identified by the students as needed to be given a second consideration. Students appreciated that as much as they learnt on their own in these lessons, there was the need to give them much more time. This is because the students thought they needed time to relax, reflect, and share ideas. Amankwaa explained that

> There are a lot of activities and we need more time to perform them. In case all members in my group have idea about what we're discussing, you need to allow each and every one to talk and share his/her idea… and all these we need time to perform the activities very well.

Akua was particularly interested in the time factor, expressing the view of most of the students that there was the need to increase the time from 60 minutes to 2 hours. An extract from Akua was:

Teacher: What can be done to help you better perform the activities?

Akua: To me the answer is time.

Teacher: What about time?

Akua: In fact the time is too small.

Teacher: ... but the time is 60 minutes?

Akua: Yes but my group is rushing and we need more time to feel free and think and share ideas.

Teacher: How many minutes should be added?

Akua: I prefer 2 hours

Only two of the students showed some signs of disagreement that the time should be increased. The students were of the view that they needed to work at a reasonable speed and not to relax so much. Ayamba explained that "the time is enough and there is no need to increase or reduce the time... the time should be the same for all the lessons". Aban explained that "I'm okay with the time and I think it is enough for the activities we did".

Some of the students made recommendation about the concept of oxidation numbers. The students felt that since the oxidation numbers played a crucial role in deducing the processes of oxidation and reduction, it was important for the concept of oxidation numbers to be treated as a lesson on its own. Owusu said that "there should be more stress on the oxidation number and if possible to be learnt separately in a different lesson. Also, Bengre felt that

> if I can't work out the oxidation numbers, I can't show oxidation or reduction or oxidising or reducing agent, in that case I think the most important thing here is understanding of oxidation numbers... so next time give us more time on oxidation numbers.

Learning through alternative conceptions was new to the students. That notwithstanding, students thought it was very helpful as they realised some of their mistakes and roots of their difficulty in leaning oxidation-reduction reactions. An extract from Kwarteng was:

Teacher: What can we do to help you better understand the concept (Chemistry)?

Kwarteng: To me the alternative conceptions.

Teacher: What do you have to say about alternative conceptions?

Kwarteng: It is new to me as science student... and you see for the first time I learnt about things we students feel is right but they are wrong.

Teacher: Okay; what do you want me to do?

Kwarteng: I wish you can talk to our teachers to also use alternative conceptions in teaching us.

Thereafter some of the students added that it was important for their teachers to deploy a teaching strategy where the alternative conceptions will play a major role in the learning process. This is because the alternative conceptions guided the learning of the new concept. Adu explained that: "I also suggest that teaching should start with alternative conceptions and should be given more time and attention because it guides us to study the new topic better".

The results show that time was an important factor in using the PTLA. However, any consideration for time should be carefully looked at to avoid giving too much time for student learning. This is because it could be counterproductive. The role of starting lessons with alternative conceptions cannot be over stressed. It is not surprising that the study had also supported that chemistry lessons should start with students' learning of alternative conceptions. It will help students to identify their alternative conceptions and make the necessary remediation.

The results from the prototype stage had shown that the PTLA can effectively influence students' conceptual understanding of oxidation-reduction reactions. There were, however, some suggestions for improvement during the teaching try-out. The suggestions were used to improve PTLA and the final design guide lines had been outlined (Appendix K) as part of the systematic reflection and documentation stage of the study.

CHAPTER FIVE

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This chapter reports on the summary, conclusions, recommendations, and suggested areas for future research. The summary reflects on the main activities of the study and the key findings in line with the stages of the design-based research approach. The conclusions and recommendations are built on the key findings. The last section of the chapter is the presentation of suggested areas for any future research in oxidation-reduction reactions.

Summary

The study was intended to design and develop an alternative way of teaching the concept of oxidation and reduction processes to enhance student conceptual understanding of oxidation-reduction reactions. A design-based research approach using quantitative and qualitative methods was employed for the study. The design-based research approach had four stages as preliminary stage, design and development stage, prototype stage, and systematic reflection and documentation stage.

Chemistry students and teachers from three schools in Ashanti Region of Ghana were involved in the study. The schools were selected from three District Assemblies in the Ashanti Region. The sample selection was achieved through stratified random sampling and simple random sampling procedures. At the preliminary stage, six teachers and 213 SHS 3 students for the 2013/2014 academic year were involved in the study. The teachers were interviewed on difficulties of teaching oxidation-reduction reactions at the high school level and the students responded to a diagnostic test on students' conception of oxidation-reduction reactions. From the outcome of the preliminary stage study, the problem with the teaching and learning of oxidation-reduction reactions was clearly defined. The alternative way, which is participatory teaching and learning approach (PTLA) for teaching and learning oxidation-reduction reactions was designed and developed. The PTLA was validated by experts in Chemistry Education and Design-Based Research and made ready for teaching try-out.

At the prototype stage, PTLA was used in eight lessons of teaching try-outs with 15 SHS 2 chemistry students in the 2015/2016 academic year. Students were simple randomly selected from one of the three schools involved at the preliminary stage. A pretest was conducted before the eight lessons and a posttest at the end of the eight lessons. At the end of each lesson, there were interactions between researcher and students to find out their views about the lesson using PTLA. This helped to establish the effectiveness of the new teaching approach on students' conceptual understanding of oxidation-reduction reactions at the SHS level.

Key findings

1. The findings from the preliminary stage study on students' alternative conceptions and other conceptual difficulties. Students had difficulties:

   a. with reduction half-reactions involving loss of electrons; decrease in oxidation state; reduction in ionic charge; and release of 'positive' charges.

b. with oxidation half-reactions involving decrease in oxidation state; gain of electrons; loss of oxygen; loss of oxygen resulting in increase oxidation state; and increase in ionic charges.

c. conceptualising ionic equation and spectator ions using oxidation number or electron transfer.

d. with oxidised species decrease in oxidation state; accept electrons; contain oxygen; loss oxygen to decrease in oxidation state; accept electrons to decrease in oxidation state; and increase in ionic charges.

e. with reduced species increase in oxidation state; loss electrons; loss electrons to change ionic charges; and loss of oxygen to result in loss of electrons; conceptualising reduced species using loss and gain of hydrogen atoms and combine concept of oxidation number and electron transfer.

f. conceptualising reducing agents using combined concept of oxidation number and oxygen transfer; combined concept of oxidation number and electron transfer; and ionic charge.

g. conceptualising oxidising agents using oxidation number; transfer of electrons; ionic charge; and oxidising agents as reduced substances.

h. conceptualising oxidation-reduction reactions using oxidation number; oxygen transfer; and simultaneous processes of oxidation and reduction.

2. The findings from the preliminary stage study on teachers' ineffective teaching of oxidation-reduction reactions were:

a. Teachers considered the teaching of the lengthy oxidation-reduction reactions as affected by quality of students and teacher knowledge of oxidation-reduction reactions and instructional strategy.

b. Teachers used various unstructured instructional strategies in teaching oxidation-reduction reactions. The instructional strategies include lectures, questions and answers, teacher-led problem solving, group assignments, and reading assignments.

c. Teachers used instructional strategies that are combination of strategies from both constructivist and behaviourist realms unknowingly. This is because teachers used lecture strategy alongside group work though they claim they are using lecture method.

d. The teachers considered oxidation-reduction reactions as difficult to teach. This was because external examinations usually require the use of electron transfer or oxidation number, teaching students to predict outcome of reaction, and balancing oxidation-reduction reactions in acidic and basic media.

e. Teachers appreciated that there were no any form of professional development programmes organised in their schools. That is there were no school-based programmes for internal professional development.

3. The findings from the prototype stage study on effectiveness of the new teaching approach on students' conceptual understanding of oxidation-reduction reactions were:

a. Students' performance in posttest was overwhelming as compared to students' performance in pretest. This is because most students (86.7%) scored each of the items in the posttest.

b. Students' mean performance (mean = 17.1, SD = 1.5) in posttest was an improved one compared to students' mean performance (mean = 5.7, SD = 3.8, $t(14) = 16.9$, $p = 0.001$) in pretest. This is because the student performance in the posttest was found to have increased compared to student performance on oxidation-reduction reactions at the beginning of teaching with large effect size of 0.976.

c. There was a very strong and positive correlation ($r = 0.9$, $p = 0.001$) between students' performance in the pretest and their performance in the posttest. This is an indication that students' performance in the pretest and posttest in the sample of students shared high percentage (81.0%) of their variance in common.

d. Students demonstrated promising improved conceptual understanding of oxidation-reduction reactions during the teaching and learning sessions using PTLA. This is because during the Forum stage of PTLA, students explained and justified positions to oxidation-reduction processes to admiration of colleague students.

e. Students' conceptual understanding of oxidation-reduction reactions improved in posttest as compared to pretest. This is because students explained and justified positions on oxidation-reduction processes very well using the concept of oxidation number.

f. Students showed no alternative conceptions or other conceptual difficulties after having experienced eight lessons on oxidation-reduction reactions with PTLA. This is because students' conceptual understanding improved lesson after lesson.

4. The findings from the prototype stage study on student views on learning oxidation-reduction reactions using PTLA were:

a. Students were satisfied with learning oxidation-reduction reactions using the PTLA. This is because the students conceptualised the concept of oxidation-reduction reactions; hence overcoming learning difficulties learning using PTLA.

b. Students viewed PTLA as being participatory in nature in relation to the involvement of students and role of the teacher in lessons. This is because it was student-centered, evaluative, and reflective.

c. Students made suggestions for improvement in the use of PTLA. The suggestions were that time for each lesson should be increased, the concept of oxidation numbers should be given all the attention, and all chemistry lessons should start with alternative conceptions.

Conclusions

The study has shown that students have difficulties in learning the concept of oxidation-reduction reactions. This confirms WAEC Chief Examiners' Reports on chemistry on students weak performance in oxidation-reduction reactions at the SHS level (WAEC, 2004; 2005; 2006; 2007; 2008; 2009; 2011; 2012; 2013) as well as other empirical studies of Barke (2012); De Jong et al. (1995); De Jong and Treagust (2002). The current study did not only confirm the students' difficulty in oxidation-reduction reactions but has shown that students show greater difficulty in the identification of species oxidised or reduced in a reaction; oxidising or reducing agents; and everyday occurrences of oxidation-reduction reactions; and less difficulty in the identification of oxidation half- and reduction half-reactions as well as the identification of ionic equation of oxidation-reduction reaction and spectator ions. The current study has further showed that not only is it difficult for students to identify oxidising agents but it is also difficult for students to identify reducing agents as well. This finding however does not support the report of Osterlund and Ekborg (2009) that it was easy for students to identify reducing agents from a given oxidation-reduction reaction.

The study has shown that students' alternative conceptions and other conceptual difficulties (such as reduction half-reactions involve loss of electrons, oxidation half-reactions involve decrease in oxidation state, oxidised substances decrease in oxidation number, and reduced species loss oxygen to result in loss of electrons) exist in learning of oxidation-reduction reactions. This is consistent with the findings of Adu-Gyamfi et al. (2015) who showed that students' alternative conceptions exist on the introduction of H_2O, H^+, and OH^- into balancing of oxidation-reduction reactions. The current study has added to the literature on students' alternative conceptions and other conceptual difficulties in oxidation-reduction reactions with the use of the four models (oxidation number, electron transfer, addition and removal of oxygen, and addition and removal of hydrogen) approach.

Studies on oxidation-reduction reactions have shown that students have difficulty in conceptualising oxidation-reduction reactions using the concept of electron transfer (Osterlund & Ekborg, 2009) and the difficulty with electron transfer is conceptualising the direction of flow of electrons. Students have an appeal for conceptualising oxidation-reduction reaction using the loss and gain of oxygen (Barke, 2012). The current study has added that not only is the oxygen transfer model appealing to students but the hydrogen model is also appealing to students as they conceptualise oxidation-reduction reaction in terms of transfer of hydrogen atoms even when the hydrogen atoms have no direct influence on the formation of new substances. Students' alternative conceptions and other conceptual difficulties in oxidation-reduction reactions using the oxidation number model are due to the difficulty in deducing correctly the oxidation state of the atoms of the substances involved in reactions. The current study has shown that students conceptualise charges of ions as the oxidation state of the atoms involved in the reaction but this is only possible when the specie is a simple ion such as Cl^-, Br^-, or Cr^{3+} but not for oxoanions such as $Cr_2O_7^{2-}$ or SO_4^{2-}. This could imply that a 'false' fifth model (ionic charge model) of oxidation-reduction reactions is evolving.

The study has further showed that there are instances when students are confused about the use of the four models of oxidation-reduction reaction (Harrison & Treagust, 1998). The study has shown that even the use of just two of the four models is a source of students' alternative conceptions and other conceptual difficulties in the aspects of oxidation-reduction reactions used in the current study. The following are such combinations: oxidation number and transfer of electrons, transfer of electrons and ionic charge, loss/gain of oxygen and hydrogen, oxidation number and ionic charge, and oxidation number and loss/gain of oxygen. The rest are oxidation number and loss/gain of hydrogen, transfer of electron and loss/gain of oxygen, and transfer of electron and loss/gain of hydrogen.

This study has revealed that students have less or no difficulty identifying a reaction as oxidation and reduction processes simultaneously but the difficulty is on how to identify and explain the simultaneous nature of oxidation and reduction processes to justify that a particular reaction is of that type. This is however, not consistent with the findings of Osterlund and Ekborg (2009) that the difficulty of students in oxidation-reduction reactions was their failure to deduce that in this type of reaction, oxidation and reduction reactions occur simultaneously.

Furthermore, the teachers' instructional strategies are weak as they provide no opportunity for students to learn from small groups, present solutions in class, and appraise their fellow student's solution to a given problem (Shen et al., 2004). The instructional strategies such as group assignment out of the classroom used by the teachers once again lack supervision from teachers. The instructional strategies such as lectures, teacher-led problem solving, and reading assignments used by the teachers could be described as inadequate as they are not based on the participatory teaching approach recommended by MOE (2010). The strategies are not structured, lack student centeredness and collaboration (Pain et al., 2011).

The study has unearthed a number of demands chemistry teachers are faced with which makes teaching oxidation-reduction reactions difficult at the high school level. Part of the difficult stems from the demand of WAEC which limits the students to the use of transfer of electrons and oxidation number; teaching students to predict an oxidation-reduction reaction by inspection; avoidance of confusion in balancing of oxidation-reduction reactions in acidic and basic media; determination of the number of moles of atoms, charges, and electrons; and lack of materials and equipment for practical work.

The PTLA used in this study is a participatory teaching and learning approach and is student-centered, evaluative, and reflective. It is evaluative and reflective on the part of students with teacher providing little support. These characteristics of the PTLA helped in building students' confidence in learning and hence, improving students' conceptual understanding of oxidation-reduction reactions. At the Insight stage of the PTLA, student alternative conceptions are deduced and used in teaching. This takes advantage of students' alternative conceptions to help them develop conceptual understanding on chemical concepts on oxidation-reduction reactions. Teaching with PTLA also ensures learner satisfaction. The study has therefore added to the literature an alternative teaching strategy (PTLA), which is effective on improving students' conceptual understanding of chemical concepts. Thus, findings of this study not only supplement findings in related and relevant studies but also add substantive information to the existing knowledge related to the teaching and learning of oxidation-reduction reactions.

Recommendations

The following recommendations are made based on the findings of the study:

1. As teachers consider oxidation-reduction reactions as difficult to teach, it is therefore recommended that chemistry teachers master the concept of oxidation-reduction reaction very well and to select the most appropriate diagnostic instruction and cognitive conflict strategies for teaching using the transfer of electron and oxidation number models to minimise students' alternative conceptions and other conceptual difficulties and enhance students' conception of the concept.
2. As teachers considered oxidation-reduction reactions as difficult to teach partly because of the limits WAEC puts on students to use only oxidation number and electron transfer models in responding to questions on the concept, it is therefore recommended that the WAEC Chemistry Chief Examiner should encourage examiners to set questions that will demand the appropriate use of any of the four models of oxidation-reduction reactions by students.
3. Since students' conceptual understanding of oxidation-reduction reactions improved as a result of the used of participatory teaching and learning approach (PTLA), it is therefore recommended that the head of the senior high school where the prototype stage study was conducted in conjunction

with the district directorate of Ghana Education Service should organise in-service training to train chemistry teachers of the school for using PTLA in teaching chemical concepts.

4. As the study took advantage of students' alternative conceptions in teaching and that students preferred that lessons start with alternative conceptions, it is therefore recommended that chemistry teachers in the SHS where the study was conducted should identify student alternative conceptions to chemical concepts and use them accordingly in lessons.
5. Since students appreciated that lessons with PTLA is student-centered, evaluative, and reflective as well as assuring learner satisfaction in learning oxidation-reduction reactions, it is therefore recommended that chemistry teachers in the school where the study was conducted should adapt to the use of PTLA in teaching chemical concepts.

Suggestions for Further Research

The study investigated student conceptual understanding of oxidation-reduction reactions at the high school level. The study however, did not consider teacher conception of oxidation-reduction reactions. It is therefore recommended that a future research is conducted to look into teacher conception of oxidation-reduction reactions as well.

The study further investigated the effectiveness of PTLA on students' conceptual understanding of oxidation-reduction reactions. However, there are other difficult chemical concepts in the high school chemistry curriculum that students need to improve their conceptual understanding in. It is therefore recommended that future research be conducted to investigate the effectiveness of PTLA on other difficult chemical concepts at the high school level.

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APPENDICES

APPENDIX A

STUDENTS' DIAGNOSTIC TEST

This diagnostic test seeks to find out your understanding of redox reactions. Please provide the responses in the spaces provided. You are to provide **reason** for each of the responses selected. Your performance will be used for research purposes only. Your identity is not required, and therefore you are to respond to the items to the best of your ability. You will be given **60** minutes to respond to the items after which your paper will be collected.

RESPOND TO ALL THE ITEMS ON THIS SAME PAPER

1. Which of the following reactions is a redox reaction?

   a. $2HCl + Zn \rightarrow ZnCl_2 + H_2$

   b. $2HCl + ZnO \rightarrow ZnCl_2 + H_2O$

   c. $2HCl + Zn(OH)_2 \rightarrow ZnCl_2 + 2H_2O$

   REASON:

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   ....

2. Which of the following substances is **oxidised** in the reaction?

   $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$

   a. Zn

   b. $CuSO_4$

   c. $ZnSO_4$

   d. Cu

REASON:

....

....

3. Which of the following substances is **reduced** in the reaction?

$Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$

a. Zn

b. $CuSO_4$

c. $ZnSO_4$

d. Cu

REASON:

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4. Which of the following substances is an **oxidising agent** in the reaction?

$Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$

a. Zn

b. $CuSO_4$

c. $ZnSO_4$

d. Cu

REASON:

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5. Which of the following substances is a **reducing agent** in the reaction?

$Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$

a. Zn

b. $CuSO_4$

c. $ZnSO_4$

d. Cu

REASON:

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6. Which of the following substances is **oxidised** in the reaction?

$Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$

a. Cl_2

b. Br^-

c. Cl^-

d. Br_2

REASON:

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7. Which of the following substances is **reduced** in the reaction?

$Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$

a. Cl_2

b. Br^-

c. Cl^-

d. Br_2

REASON:

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8. Which of the following substances is an **oxidising agent** in the reaction?

$Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$

a. Cl_2

b. Br^-

c. Cl^-

d. Br_2

REASON:

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9. Which of the following substances is a **reducing agent** in the reaction?

$Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$

a. Cl_2

b. Br^-

c. Cl^-

d. Br_2

REASON:

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10. A piece of copper metal was folded to form a small envelope and heated with a flame; the flame outside the copper metal turned black, after opening the envelope, the inside remained copper-coloured.

a. Combustion reaction has occurred

b. The outside was made from black soot

c. A redox reaction has occurred

d. Copper atom has changed colour

REASON:

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11. For the production of iron in the blast furnace, iron oxide (Fe_3O_4) and coal (carbon) are necessary, by heating the mixture strongly; the liquid iron is running out with glaring light.

a. Carbon was a catalyst

b. A redox reaction has occurred

c. Iron oxide has reduced

d. Iron oxide has decomposed into elements

REASON:

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12. The surface of metallic iron ship at the shore of the Atlantic Ocean near Cape Coast combined with oxygen in an open air and after sometimes, in the presence of carbonic acid (H_2CO_3), developed a brownish colour.

a. Combustion of iron has occurred

b. Iron metal has changed colour

c. A redox reaction has occurred

REASON:

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13. Identify the reduction half reaction from the reaction.

$Mg + Zn(NO_3)_2 \rightarrow Mg(NO_3)_2 + Zn$

a. $Mg \rightarrow Mg^{2+}$

b. $Zn^{2+} \rightarrow Zn$

c. $Mg + Zn^{2+} \rightarrow Mg^{2+} + Zn$

REASON:

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14. Identify the oxidation half reaction from the reaction.

$Mg + Zn(NO_3)_2 \rightarrow Mg(NO_3)_2 + Zn$

a. $Mg \rightarrow Mg^{2+}$

b. $Zn^{2+} \rightarrow Zn$

c. $Mg + Zn^{2+} \rightarrow Mg^{2+} + Zn$

REASON:

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15. The ionic equation for [$Mg + Zn(NO_3)_2 \rightarrow Mg(NO_3)_2 + Zn$] is:

a. $Mg \rightarrow Mg^{2+}$

b. $Zn^{2+} \rightarrow Zn$

c. $Mg + Zn^{2+} \rightarrow Mg^{2+} + Zn$

REASON:

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16. Identify the spectator ion from the reaction.

$Mg + Zn(NO_3)_2 \rightarrow Mg(NO_3)_2 + Zn$

a. Mg^{2+}

b. Zn^{2+}

c. NO_3^-

REASON:

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17. Identify the **reduction half** reaction in the following reaction:

$Fe^{2+} + Cr_2O_7^{2-} \rightarrow Fe^{3+} + Cr^{3+}$

a. $Fe^{2+} \rightarrow Fe^{3+}$

b. $Cr_2O_7^{2-} \rightarrow Cr^{3+}$

REASON:

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18. Identify the **oxidation half** reaction in the following reaction:

$Fe^{2+} + Cr_2O_7^{2-} \rightarrow Fe^{3+} + Cr^{3+}$

a. $Fe^{2+} \rightarrow Fe^{3+}$

b. $Cr_2O_7^{2-} \rightarrow Cr^{3+}$

REASON:

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APPENDIX B

PRETEST ITEMS

Respond to all the Items on this Same Paper

1. Which of the following reactions is a redox reaction?

   a. $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$

   b. $MgO + 2HCl \rightarrow MgCl_2 + H_2O$

   c. $Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3$

   REASON:

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2. Which of the following species is **oxidised** in the reaction?

   $2Br^- + Sn^{2+} \rightarrow Br_2 + Sn$

   a. Br^-

   b. Sn^{2+}

   c. Br_2

   d. Sn

   REASON:

   ....

   ....

3. Which of the following species is **reduced** in the reaction?

   $2Br^- + Sn^{2+} \rightarrow Br_2 + Sn$

   a. Br^-

   b. Sn^{2+}

c. Br_2

d. Sn

REASON:

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4. Which of the following species is an **oxidising agent** in the reaction?

$Ag + Ni^{2+} \rightarrow Ag^{+} + Ni$

a. Ag

b. Ni^{2+}

c. Ag^{+}

d. Ni

REASON:

....

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5. Which of the following species is a **reducing agent** in the reaction?

$Ag + Ni^{2+} \rightarrow Ag^{+} + Ni$

a. Ag

b. Ni^{2+}

c. Ag^{+}

d. Ni

REASON:

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6. Identify the reduction half reaction from the following reaction:

   $ClO_3^- + Cl^- \rightarrow Cl_2 + ClO_2$

   a. $ClO_3^- \rightarrow ClO_2$

   b. $Cl^- \rightarrow Cl_2$

   c. $ClO_3^- + Cl^- \rightarrow Cl_2 + ClO_2$

   REASON:

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7. Identify the oxidation half reaction from the following reaction:

   $ClO_3^- + Cl^- \rightarrow Cl_2 + ClO_2$

   a. $ClO_3^- \rightarrow ClO_2$

   b. $Cl^- \rightarrow Cl_2$

   c. $ClO_3^- + Cl^- \rightarrow Cl_2 + ClO_2$

   REASON:

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8. Identify the reduction half reaction from the following reaction:

   $2HCl + Zn \rightarrow ZnCl_2 + H_2$

   a. $2H^+ \rightarrow H_2$

   b. $Zn \rightarrow Zn^{2+}$

   c. $2H^+ + Zn \rightarrow Zn^{2+} + H_2$

REASON:

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9. Identify the oxidation half reaction from the following reaction:

$2HCl + Zn \rightarrow ZnCl_2 + H_2$

a. $2H^+ \rightarrow H_2$

b. $Zn \rightarrow Zn^{2+}$

c. $2H^+ + Zn \rightarrow Zn^{2+} + H_2$

REASON:

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10. Identify the spectator ion from the following reaction.

$2HCl + Zn \rightarrow ZnCl_2 + H_2$

a. $2H^+$

b. Zn^{2+}

c. Cl^-

APPENDIX C

POSTTEST ITEMS

Respond to all the Items on this Same Paper

1. Identify the spectator ion from the following reaction:

   $2HCl + Zn \rightarrow ZnCl_2 + H_2$

   a. $2H^+$

   b. Zn^{2+}

   c. Cl^-

2. Which of the following species is **oxidised** in the reaction?

   $2Br^- + Sn^{2+} \rightarrow Br_2 + Sn$

   a. Br^-

   b. Sn^{2+}

   c. Br_2

   d. Sn

   REASON:

   ....

   ....

3. Which of the following species is an **oxidising agent** in the reaction?

   $Ag + Ni^{2+} \rightarrow Ag^+ + Ni$

   a. Ag

   b. Ni^{2+}

   c. Ag^+

   d. Ni

REASON:

....

....

4. Which of the following reactions is a redox reaction?

a. $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$

b. $MgO + 2HCl \rightarrow MgCl_2 + H_2O$

c. $Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3$

REASON:

....

....

5. Which of the following species is a **reducing agent** in the reaction?

$Ag + Ni^{2+} \rightarrow Ag^{+} + Ni$

a. Ag

b. Ni^{2+}

c. Ag^{+}

d. Ni

REASON:

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6. Identify the oxidation half reaction from the following reaction:

$ClO_3^{-} + Cl^{-} \rightarrow Cl_2 + ClO_2$

a. $ClO_3^{-} \rightarrow ClO_2$

b. $Cl^{-} \rightarrow Cl_2$

c. $ClO_3^- + Cl^- \rightarrow Cl_2 + ClO_2$

REASON:

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7. Identify the reduction half reaction from the following reaction:

$2HCl + Zn \rightarrow ZnCl_2 + H_2$

a. $2H^+ \rightarrow H_2$

b. $Zn \rightarrow Zn^{2+}$

c. $2H^+ + Zn \rightarrow Zn^{2+} + H_2$

REASON:

....

....

8. Which of the following species is **reduced** in the reaction?

$2Br^- + Sn^{2+} \rightarrow Br_2 + Sn$

a. Br^-

b. Sn^{2+}

c. Br_2

d. Sn

REASON:

....

....

9. Identify the reduction half reaction from the following reaction:

$ClO_3^- + Cl^- \rightarrow Cl_2 + ClO_2$

a. $ClO_3^- \rightarrow ClO_2$

b. $Cl^- \rightarrow Cl_2$

c. $ClO_3^- + Cl^- \rightarrow Cl_2 + ClO_2$

REASON:

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10. Identify the oxidation half reaction from the following reaction:

$2HCl + Zn \rightarrow ZnCl_2 + H_2$

a. $2H^+ \rightarrow H_2$

b. $Zn \rightarrow Zn^{2+}$

c. $2H^+ + Zn \rightarrow Zn^{2+} + H_2$

REASON:

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APPENDIX D

TEACHERS' INTERVIEW GUIDE

1. Do you teach redox reactions to your students?
2. How often do you teach your students redox reactions?
3. Explain how you teach redox reactions to your students.
4. What should be the best way for the teaching of redox reactions?
5. Are there any identifiable challenges associated with the teaching of redox reactions?
6. Explain how these identifiable challenges could affect the teaching of redox reactions.
7. Explain what should be done to reduce the effects of these identifiable challenges on teaching of redox reactions.

APPENDIX E

STUDENTS' INTERVIEW GUIDE

1. Explain why you selected this option as your answer to this question.
2. Explain why you consider this as oxidising or reducing agent.
3. Explain why you consider this as oxidation or reduction half of the reaction.
4. Explain the role of H^+, OH^-, and H_2O in balancing redox reactions.

APPENDIX F

PROTOTYPE STAGE INTERVIEW GUIDE

1. How do assess today's lesson; was it a success or failure?
2. Explain why you consider it a success or failure.
3. Is the lesson participatory enough for you as a student?
4. Explain why you consider the lesson as participatory.
5. What do make of the role of the teacher in this lesson compared to other Chemistry lessons you have attended?
6. What can be done to enhance students' understanding in oxidation-reduction reactions?

APPENDIX G

STUDENTS' CONCEPTIONS OF OXIDATION-REDUCTION PROCESSES

Lesson 1

The aim of the lesson is to find out students' conceptions of processes or reactions termed as oxidation and reduction. To be able to achieve this, the following activities will be performed.

Insight stage 1: Students will be asked to explain in written form the meaning of oxidation process and reduction process. The question will read: "Explain the meaning of the following concepts in redox reactions: a) oxidation and b) reduction." The students will respond to the question individually. The time for this activity will be 20 minutes.

Interaction stage 1: After the 20 minutes, students will form groups of three members each. Each group will receive a worksheet on students' conceptions on the processes of oxidation and reduction. Students will discuss among themselves each student's conceptions on oxidation and reduction processes, in the light of the given alternative conceptions, to accept or not to accept. The activity will be 20 minutes. Thereafter the teacher will discuss the conception of oxidation and reduction processes with students for 10 minutes.

Insight stage 2: Students will be engaged in another activity. In this activity, students are expected to identify a given reaction as oxidation-reduction reaction or not. The question for the second activity will read: "Identify redox reaction in each of the following reactions and give reasons for your answer:

d. $2HCl + Zn \rightarrow ZnCl_2 + H_2$

e. $2HCl + ZnO \rightarrow ZnCl_2 + H_2O$

f. $2HCl + Zn(OH)_2 \rightarrow ZnCl_2 + 2H_2O$"

REASON:

....

....

Students will also perform the second activity individually in 15 minutes. After the 15 minutes, the teacher will provide students with some alternative conceptions associated with identification of a reaction as oxidation-reduction reactions for the Interaction stage of the second activity.

Interaction stage 2: Students will discuss in groups each student's conception, in the light of the given alternative conceptions on identification of oxidation-reduction reactions to accept or not to accept such alternative conceptions. The interaction will be 15 minutes.

Thereafter, the teacher will discuss with students the conception of oxidation-reduction reactions for 10 minutes. The aim of students' interaction with the teacher is to stress the correct conception of a given reaction as oxidation-reduction reaction. The teacher will use further examples to help students develop the correct conceptual understanding of oxidation and reduction processes.

Lesson 2

The aim of this session is to provide students with the opportunity of using the knowledge acquired in oxidation and reduction processes. It will further help students to expand and modify their thinking and ideas in oxidation and reduction processes.

Task stage: The teacher will revise with students the aspect of oxidation-reduction reactions learnt in the previous lessons. Students will sit in groups of three members each. The worksheet containing the problem of the day will be given to the groups. Students will interact among themselves using Worksheet 1 to find a solution to the problem of the day. The activity will be 30 minutes.

Worksheet 1

Instruction: The following are a number of chemical reactions. You are to study them carefully using the concept of oxidation number.

$3Mg + N_2 \rightarrow Mg_3N_2$

$CO_2 + H_2O \rightarrow H_2CO_3$

$NH_3 + HCl \rightarrow NH_4Cl$

$2Zn(NO_3)_2 \rightarrow 2ZnO + 4NO_2 + O_2$

$2KBr + Cl_2 \rightarrow 2KCl + Br_2$

$Fe + 2HCl \rightarrow FeCl_2 + H_2$

$HCl + AgNO_3 \rightarrow HNO_3 + AgCl$

$FeCl_2 + ½Cl_2 \rightarrow FeCl_3$

$CuO + H_2 \rightarrow H_2O + Cu$

$NaOH + HCl \rightarrow NaCl + H_2O$

You are to analyse the reactions using the statements in the table below.

Group Number: .... **Date:** ....

1. Identify the reactions that are redox reactions from the given reactions above.	
2. Identify the substance increasing in oxidation number in the reactions in (1) above.	
3. Identify the substances decreasing in oxidation number in the reactions in (1) above.	
4. Draw your conclusion justifying why the reactions selected in (1) above are redox.	

Forum stage: After the 30-minute period of an attempt of students looking for solution to the problem of the day, a member from each group will present and explain their solution to the class. Students will raise questions about the solution presented. After all the groups' presentation of the solution, students will judge the most appropriate solution to the problem of the day. The time for the presentations will be 45 minutes.

The teacher will finally stress the most appropriate solution in 15 minutes. Where there is a shortfall in the groups' presentations, the teacher will help students identify and modify their thinking and ideas. The teacher will also respond to students' issues on areas they need clarification.

APPENDIX H

STUDENTS' CONCEPTIONS OF HALF REACTIONS

Lesson 3

The aim of the lesson is to find out students' conceptions of oxidation half reactions and reduction half reactions. It will further help to find students' conceptions of oxidised and reduced substances and oxidising and reducing agents in oxidation-reduction reactions. To be able to achieve this, the following activities will be performed.

Insight stage 1: Students will be given Worksheet 2 containing some alternative conceptions on oxidised substance and oxidising agents and reduced substance and reducing agents to identify themselves with. Students will first identify themselves with the statements as individual students in 20 minutes.

Worksheet 2

Instruction: The following are a number of statements relating to oxidised and oxidising agents and reduced and reducing agents. Study them carefully. Indicate whether you **accept** the statement as correct or you **do not accept** the statement as correct.

Group Number: .... **Date:** ....

1. A substance with positive charge is an oxidising agent.	
2. Oxidising agent is a substance that is oxidised by losing electrons.	
3. Oxidising agent accepts oxygen	

atoms to change oxidation state.	
4. A substance with oxygen atom in its molecule is oxidised.	
5. An oxidised substance is a substance whose ionic charge increases as it accepts electrons.	
6. Reducing agent is a substance that accepts electrons.	
7. Reducing agent accepts oxygen atoms to change oxidation state.	
8. Reducing agent is a substance that does not have oxygen in its molecule.	
9. A reduced substance is the substance that loses electrons to change its charge.	
10. Explain the meaning of an oxidising agent (if different from anyone of the above).	
11. Explain the meaning of an oxidised substance (if different from any of the above).	
12. Explain the meaning of reducing agent (if different from any of the	

above).	
13. Explain the meaning of reduced substance (if different from any of the above).	

Interaction stage 1: After the 20 minutes, students will form groups of three members each. In the groups, students will discuss among themselves the alternative conceptions and each student's conceptions of oxidising/reducing agents and reduced/oxidised substances. Students will discuss to accept or not to accept such conceptions in 20 minutes.

In the next 10 minutes, the teacher will discuss with students the conception of oxidising/reducing agents and reduced/oxidised substance. The teacher will use sample reactions to bring out the conception of oxidising/reducing agents and reduced/oxidised substances.

Insight stage 2: Students will be engaged in a second activity on conception of half reactions. In this activity, students are expected to deduce the half reactions of some given reactions. The question for the activity will read: "Deduce the a) oxidation half and b) reduction half of the following reactions and give reasons for your answer:

a. $2HCl + Zn \rightarrow ZnCl_2 + H_2$

REASON:

....

....

b. $CuO + H_2 \rightarrow H_2O + Cu$"

REASON:

....

....

Students will perform the second activity in 15 minutes. After the 15 minutes, students will receive Worksheet 3 on alternative conceptions of half reactions for the Interaction stage of the second activity.

Worksheet 3

Instruction: The following are a number of statements relating to oxidation half and reduction half. Study them carefully. Indicate whether you **accept** the statement as correct or you **do not accept** the statement as correct.

Group Number: .... **Date**: ....

1. Oxidation half involves gain of electrons.	
2. Oxidation half involves gain of electrons to increase in oxidation state of substance.	
3. Reduction half involves lost of electrons.	
4. A positive ion gives an indication of reduction reaction.	
5. Removal of an oxoanion is an indication of reduction half.	

6. Reduction half involves decrease in oxidation state caused by loss of electrons	
7. Reduction half involves decrease in oxidation state as a result of loss of oxygen atoms.	
8. Explain the meaning of oxidation half (if different from any of the above).	
9. Explain the meaning of reduction half (if different from any of the above).	

Interaction stage 2: Students will discuss, in groups, each student's conception of oxidation half and reduction half reactions, in the light of the given alternative conceptions. Students will discuss to accept or not to accept the alternative conceptions of half reactions. The interaction will be 15 minutes.

Thereafter, the teacher will discuss with students the conception of half reactions for the next 10 minutes. The teacher will use further sample reactions to assist students develop conceptual understanding of oxidation half and reduction half reactions.

Lesson 4

The aim of Lesson 4 is to provide students with the opportunity of using the knowledge acquired on half reactions. This will help students to expand and modify their thinking and ideas on half reactions.

Task stage: The teacher will revise previous lesson on half reactions with students. Students will sit in their groups of three members each. Students will receive Worksheet 4 containing the problem of the day. Students will interact among group members to find solution to the problem of the day using the worksheet. The activity will be 30 minutes.

Worksheet 4

Instruction: The following are a number of reactions and you are to use the concept of oxidation number to identify the oxidation half- and reduction half-reactions among them.

1. $2KBr + Cl_2 \rightarrow 2KCl + Br_2$
2. $Fe + 2HCl \rightarrow FeCl_2 + H_2$
3. $2KClO_3 \rightarrow 2KCl + 3O_2$
4. $Fe^{2+} + Cr_2O_7^{2-} \rightarrow Fe^{3+} + Cr^{3+}$

You are to analyse the reactions using the statements in the table below.

Group Number: .... **Date**: ....

1. Identify the oxidised species and oxidising agent in reaction (1) above using oxidation number.	

2. Identify the reduced species and reducing agent in reaction (1) above using oxidation number.	
3. Identify the oxidised species and oxidising agent in reaction (2) above using oxidation number. 4. Identify the reduced species and reducing agent in reaction (2) above using oxidation number.	
5. Identify the oxidised species and oxidising agent in reaction (3) above using oxidation number. 6. Identify the reduced species and reducing agent in reaction (3) above using oxidation number.	
7. Identify the oxidised species and oxidising agent in reaction (4) above using oxidation number. 8. Identify the reduced species and reducing agent in reaction (4) above	

using oxidation number.	
9. Write down the half reactions and the ionic equation for each of the given reactions.	1.a. oxidation half b. reduction half c ionic equation 2.a. oxidation half b. reduction half c ionic equation 3.a. oxidation half b. reduction half c ionic equation 4.a. oxidation half b. reduction half

	c. ionic equation
10. Draw your conclusion justifying the concept of half reactions.	

Forum stage: After the 30-minute period of an attempt of students looking for solution to the problem of the day, a member from each group will present and explain their solution to the class. Students will raise questions about the solution presented. After all the groups' presentation of the solution, students will judge the most appropriate solution to the problem of the day. The time for the presentations will be 45 minutes.

The teacher will finally stress the most appropriate solution in 15 minutes. Where there is a shortfall in the groups' presentations on half reactions, the teacher will help students identify and modify their thinking and ideas. The teacher will also respond to students' issues on areas that need clarification.

APPENDIX I

STUDENTS' CONCEPTION OF BALANCING OXIDATION-REDUCTION REACTIONS

Lesson 5

The aim of the lesson is to find out students' conceptions of balancing oxidation-reduction reactions in a basic medium. The ion-electron approach of balancing oxidation-reduction reactions in basic medium will be the main approach for consideration in the lesson. To be able to achieve this, the following activities will be performed.

Insight stage: Students will receive Worksheet 5 containing some alternative conceptions of balancing oxidation-reduction reactions. Students will identify themselves with the given alternative conceptions first as individual students. The activity will be 20 minutes.

Worksheet 5

Instruction: The following are a number of statements relating to balancing of redox reactions. Study them carefully. Indicate whether you **accept** the statement as correct or you **do not accept** the statement as correct.

Group Number: ……………………………….. **Date**: ………………………………

1. The half reaction which involves removal of oxygen atoms (from oxoanions) is the reduction half-reaction.	
2. The net charge of an oxoanion is	

considered as the oxidation state of the central atom as it were in the case of simple ions.	
3. Balancing redox reactions is like balancing any other reaction where only atoms are balanced.	
4. In balancing redox reactions, H^+ ions and OH^- ions are added because the reactions occur in acidic and basic media.	
5. In balancing redox reactions, H_2O is added to dilute the acidic concentration of the reaction.	
6. In balancing redox reactions, H_2O is first added to take care of the H atoms.	
7. In balancing redox reactions in base, H_2O is added to react with the base.	
8. Explain briefly any other idea you have about balancing redox reactions.	

Interaction stage 1: After the 20 minutes, students will form groups of three members each. In each group students will discuss among themselves the alternative conceptions and each student's conception of balancing oxidation-reduction reactions. Students will discuss to accept or not to accept the alternative conceptions in 20 minutes.

The teacher will discuss with students these alternative conceptions of balancing oxidation-reduction reactions to help address them. In addressing the alternative conceptions, the teacher will discuss with students the conception of the stages in balancing oxidation-reduction reactions in basic medium. The activity will be 10 minutes.

As students remain in their groups, they will receive Worksheet 6 on worked sample of balancing oxidation-reduction in basic medium. Students will discuss among themselves the concept of balancing oxidation-reduction reactions in basic medium. The activity will be 20 minutes.

Worksheet 6

Instruction: The following are list of equations; study them carefully:

Sample reactions:

i. $MnO_4^- + I^- \rightarrow MnO_2 + I_2$

ii. $6I^- \rightarrow 3I_2 + 6e^-$

$MnO_4^- + 4H_2O + 6e^- \rightarrow 2MnO_2 + 8OH^-$

iii. $2I^- \rightarrow I_2$

$4H^+ + MnO_4^- \rightarrow MnO_2 + 2H_2O$

$4H^+ + MnO_4^- + 4OH^- \rightarrow MnO_2 + 2H_2O + 4OH^-$

iv. $2I^- \rightarrow I_2 + 2e^-$

$MnO_4^- + 2H_2O + 3e^- \rightarrow MnO_2 + 4OH^-$

v. $2MnO_4^- + 6I^- + 4H_2O \rightarrow 2MnO_2 + 3I_2 + 8OH^-$

vi. $I^- \rightarrow I_2$

$MnO_4^- \rightarrow MnO_2$

You are to study the steps in the table below and match the samples equations with the steps.

Group Number: .... **Date**: ....

1. Write the unbalanced equation for the reaction in ionic form.	
2. Separate the equation into two half-reactions.	
3. Balance the atoms except O and H in each half-reaction separately.	
4. Add H_2O to balance the O atoms and balance any H^+ with OH^-.	
5. Add electrons to one side of each half-reaction to balance the charges. If necessary, equalise the number of electrons in the two half-reactions by multiplying one or both half-reactions by appropriate coefficients.	
6. Add the two half-reactions together and balance the final equation by inspection. The electrons on both sides must cancel.	

7. Verify that the equation contains the same types and numbers of atoms and the same changes on both sides of the equation.	

After the 20 minutes, the teacher will discuss the conception of balancing oxidation-reduction reactions in basic medium using the worked example. The teacher will use further example to stress the conception of balancing oxidation-reduction reaction in basic medium. The activity will be 20 minutes.

Lesson 6

The aim of Lesson 6 is to provide students with the opportunity of using the knowledge acquired on balancing oxidation-reduction reactions in basic medium in balancing such reactions. This will help students to expand and modify their thinking and ideas in balancing oxidation-reduction reactions in basic medium.

Task stage: The teacher will revise previous lesson on balancing oxidation-reduction reactions in basic medium with students. Students will sit in their groups of three members each. Students will receive Worksheet 7 containing the problem of the day on balancing oxidation-reduction reactions. Students will interact among group members to find solution to the problem of the day using the worksheet. The activity will be 30 minutes.

Worksheet 7

Instruction: Read over carefully the statement below.

A was a solution of $KMnO_4$ of unknown concentration and B was 0.05M solution of sodium ethanoate ($Na_2C_2O_4$). About $10cm^3$ of B was pipette into a conical flask and about $15cm^3$ of dil. H_2SO_4 was added. The mixture was then heated to about 70°C and titrated while still hot with A. When the temperature fell below 60°C, it was heated again and the titration continued.

Write a balance equation for the standardisation of $KMnO_4$ using $Na_2C_2O_4$ from MnO_4^-/Mn^{2+} and $C_2O_4^{2-}/CO_2$ using the guide in the table below.

Group Number: .... **Date:** ....

1. Write the unbalanced equation for the reaction in ionic form.	
2. Separate the equation into two half-reactions.	
3. Balance the atoms except O and H in each half-reaction separately.	
4. For reactions in acidic medium, add H_2O to balance the O atoms and H^+ to balance the H atoms.	
5. Add electrons to one side of each half-reaction to balance the charges. If necessary, equalise the number of electrons in the two half-reactions by multiplying one or both half-reactions by appropriate coefficients.	

6. Add the two half-reactions together and balance the final equation by inspection. The electrons on both sides must cancel.	
7. Verify that the equation contains the same types and numbers of atoms and the same changes on both sides of the equation.	
8. Draw your conclusion justifying the solution to the problem you have solved.	

Forum stage: After the 30-minute period of an attempt of students looking for solution to the problem of the day, a member from each group will present and explain their solution to the class. Students will raise questions about the solution presented. After all the groups' presentation of the solution, students will judge the most appropriate solution to the problem of the day. The time for the presentations will be 45 minutes.

The teacher will finally stress the most appropriate solution in 15 minutes. Where there is a shortfall in the groups' presentations on balancing oxidation-reduction reactions, the teacher will help students identify and modify their thinking and ideas. The teacher will also respond to students' issues on areas that need clarification.

APPENDIX J

STUDENTS' CONCEPTIONS OF EVERYDAY APPLICATION OF OXIDATION-REDUCTION PROCESSES

Lesson 7

The aim of Lesson 7 is to find out students' conceptions of application of the concept of oxidation-reduction processes in everyday occurrences. It will give students opportunity to analyse some phenomena in their environment using the concept of oxidation and reduction processes. To be able to achieve this, the following activities will be performed.

Insight stage 1: Students will receive Worksheet 8 containing some questions on rusting of iron. Students will first respond to the questions as individual students. The activity will be 15 minutes.

Worksheet 8

Instruction: The following are a number of questions on rusting of metals. Read over them carefully. The chemical equation for rusting of iron is:

$Fe^{2+}{}_{(aq)}$ + $O_{2(g)}$ + $xH_2O_{(l)} \rightarrow Fe_2O_3.xH_2O_{(s)}$ + $8H^+{}_{(aq)}$

You are to analyse the reaction using the statements in the table below.

Group Number: .... **Date**: ....

1. Identify the specie oxidised in the reaction. b. Give reason for your answer.	
2. Identify the specie reduced in the reaction.	

b. Give reason for your answer.	
3. Identify the oxidising agent in the reaction. b. Give reaction for your answer.	
4. Identify the reducing agent in the reaction. b. Give reason for your answer.	
5. Deduce the oxidation half of the reaction. b. Give reason for your answer.	
6. Deduce the reduction half of the reaction. b. Give reason for your answer.	
7. Explain briefly the concept of rusting of metals.	

Interaction stage 1: After the 15 minutes, students will form groups of three members each. Each group will receive Worksheet 9 on students' conceptions on the processes of rusting of iron. Students will discuss among themselves each student's conceptions of oxidation and reduction processes of rusting of iron, in the light of the given alternative conceptions, to accept or not to accept. The activity will be 20 minutes. Thereafter the teacher will discuss the conception of rusting of iron as oxidation and reduction processes with students for 10 minutes.

Worksheet 9

Instruction: The following are a number of statements relating to rusting of metals. Study them carefully. Indicate whether you **accept** the statement as correct or you **do not accept** the statement as correct.

Group Number: .... **Date**: ....

1. Oxygen combines with iron to form the brownish colour on it.	
2. Rusting is a change of colour on metals.	
3. The oxygen atom burns the surface of the metal.	
4. H_2O added oxygen to iron surface to change its colour.	
5. Explain any other idea you have about rusting of iron.	

In the next 10 minutes, the teacher will discuss with students the conception of rusting of iron as an oxidation-reduction process. The teacher will use the concept of oxidation number or electron transfer to help students develop conceptual understanding of rusting of iron as an oxidation-reduction process.

Insight stage 2: Students will be engage in a second activity on heating of an envelope of copper metal with a flame. The teacher will start the demonstration experiment by asking students to write down their expectations. Thereafter, the teacher will heat the copper envelop with a flame from Bunsen burner. After some time, the teacher will open up the copper envelop for students' observations. Students are encouraged to write down their observations individually. The activity will be 10 munities.

Interaction stage 2: Students will receive Worksheet 10 on alternative conceptions of combustion of copper metal. Students will discuss in groups each student's conception of combustion of copper metal as oxidation and reduction processes, in the light of some alternative conceptions of combustion of copper metal. Students will discuss to accept or not to accept the alternative conceptions of combustion of copper metal. The interaction will be 15 minutes.

Worksheet 10

Instruction: The following are a number of statements relating to combustion of copper metal. Study them carefully. Indicate whether you **accept** the statement as correct or you **do not accept** the statement as correct.

Group Number: .... **Date**: ....

1. Copper turned black as a result of combustion.	
2. Copper turned black as a result of oxygen in the flame.	
3. The outside of copper envelop turned	

black because of the soot.	
4. The colour of copper has changed in the cause of heating.	
5. Oxygen has oxidised copper.	
6. Copper turned black because there was loss and gain of hydrogen	
6. Explain any other idea you have about combustion of copper metal in a flame.	

Thereafter, the teacher will discuss with students the conception of combustion of copper metal as oxidation-reduction processes for the next 15 minutes. The teacher will use the concept of oxidation number or electron transfers to assist students develop conceptual understanding of combustion of copper metal as oxidation and reduction processes.

Lesson 8

The aim of Lesson 8 is to provide students with the opportunity of using the knowledge of oxidation-reduction processes in everyday occurrences. This will help students to appreciate that the concept of oxidation-reduction processes are applicable in their lives and the environment.

Task stage: The teacher will revise previous lesson on rusting of iron and combustion of copper metal with students. Students will sit in their groups of three members each. Students will receive Worksheet 11 containing the problem of the day. Students will interact among group members to find solution to the problem of the day using the worksheet. The activity will be 30 minutes.

Worksheet 11

Instruction: Read over carefully the statement below.

Most individuals, families, and institutions in Ghana are currently using generators to burn fuel to generate electricity; as a result of load shedding process. The generators can only work to 30% efficiency in converting chemical energy in the fuel to electrical energy. To avoid waste in generation of electricity from the use of generators, fuel cells which use hydrogen-oxygen as fuel to generate 90% efficiency can be used.

In fuel cells, hydrogen and oxygen are mixed in alkaline solution (KOH) to generate electricity according to the following reactions:

$O_{2(g)} + 2H_2O_{(l)} + 4e^- \rightarrow 4OH^-_{(aq)}$

$2H_{2(g)} + 4OH^-_{(aq)} \rightarrow 4H_2O_{(l)} + 4e^-$

You are to analyse the reactions using the statements in the table below.

Group Number: .... **Date:** ....

1. Identify the oxidation half process. b. Give reason for you answer.	
2. Identify the reduction half process. b. Give reason for your answer.	
3. Write the overall reaction for the oxidation and reduction processes.	
4. Explain how the fuel cell generates	

electricity as oxidation and reduction processes using the concept of oxidation number or electron transfer.	

Forum stage: After the 30-minute period of an attempt of students looking for solution to the problem of the day, a member from each group will present and explain their solution to the class. Students will raise questions about the solution presented. After all the groups' presentation of the solution, students will judge the most appropriate solution to the problem of the day. The time for the presentations will be 45 minutes.

The teacher will finally stress the most appropriate solution in 15 minutes. Where there is a shortfall in the groups' presentations on the processes of oxidation and reduction in the used hydrogen-oxygen fuel cell, the teacher will help students identify and modify their thinking and ideas. The teacher will also respond to students' issues on areas that need clarification.

APPENDIX K

DESIGN GUIDELINES FOR IMPROVING STUDENT CONCEPTION IN CHEMICAL CONCEPTS

An outcome of the design-based research approach adopted for the study has been the deduction of a body of design guidelines that could serve as a guide for teachers and researchers in Chemistry Education in their development in designing instructional sequence for teaching chemical concepts at the SHS level. From the study, the following design guidelines have been deduced:

1. The usage of instructional sequence, where strategies are selected when needed, developed from existing strategies is very important. The sequence is important because no single strategy is sufficiently enough for a complex process and every student has a peculiar learning style. This will help other researchers and designers to develop similar interventions for teaching and learning of chemical concepts.
2. Students learn by collaboration, action, and reflection in an instruction which is built on constructivist learning theory. Collaboration is seen from groups and teams formed during instruction. The interactions in groups and teams will help members to learn to agree, disagree, and have mutual respect for the views of each other. Students actively make meaning in social learning environments and reflect individually on their experiences to imitate their use. Other researchers and designers could design and develop interventions for teaching chemical concepts that incorporate the attributes of collaboration, action, and reflection

3. The involvement of students in design and development of instruction, in which students work with researchers, is an important means to design an instruction for end users. This approach helps designers to design instruction that suit the learning needs of students at the said level.
4. The eight lessons developed for the teaching try-outs are very important outcomes of the study. The lessons could guide researchers and instructional designers to develop similar lessons and to link theoretical learning experiences to practical activities designing interventions.
5. Scaffolds and teaching try-outs with students using prepared materials help to validate the new intervention. This is because in theory the intervention could work but not in practice. Hence, in designing instruction for teaching chemical concepts teaching try-out as well as feedback from students should be crucial point where opportunities are provided for improvement in the intervention.