UNIVERSITY OF CAPE COAST

DEVELOPMENT OF TEACHING AND LEARNING MATERIAL FOR CHEMICAL FORMULAE AND CHEMICAL EQUATIONS

REXFORD BAAH

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BY

REXFORD BAAH

Thesis submitted to the Department of Science Education of the Faculty of Science and Technology Education, College of Education Studies, University of Cape Coast, in partial fulfillment of the requirements for the award of Doctor of Philosophy Degree in Science Education.

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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:............................

Name: Rexford Baah

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.

Principal Supervisor's Signature........................ Date 30/11/2017

Name: Professor Joseph Ghartey Ampiah

Co-Supervisor's Signature .... Date 30/11/2017

Name: Professor Theophilus Aquinas Ossei-Anto

ABSTRACT

The West African Examinations Council has since the year 1994, alluded consistently to students inability to write correct chemical formulae and chemical equations at the SSSCE/WASSCE chemistry examinations. Studies have also shown that the ability required to write chemical equations is not a simple one and that, students' persistent difficulties in solving stoichiometric problems are partly associated with their inability to write correct chemical formulae and represent chemical equations correctly. Hence, this study developed a teaching and learning material for chemical formulae and chemical equations of inorganic compounds. Three form 2 and three form 1 science classes selected from the Cape Coast Metropolis for the 2012/2013 academic year were initially sampled randomly for the pre-test and after the pre-test, one form 2 and one form 1 science classes were selected for the development of the teaching and learning material. The two main designs used in this study were cross-sectional survey and one group pre-test-post-test experimental design and the two main instruments used were achievement tests and an open ended questionnaire. One of the key findings was that the concept of valency and the role it plays in the writing of chemical formulae was poorly understood by both form 1 and form 2 science students. Also, the teaching and learning material developed in this study helped improve the conceptions and performance of the students as the mean vales of all the post-tests in this study were significantly higher than their pre-test mean values. One recommendation urges chemistry teachers to use charts of the periodic table and oxidation numbers when teaching chemical formulae and chemical equations.

KEY WORDS

Pedagogical content knowledge (PCK)

Chemical formulae

Chemical equations

Alternative conceptions

Iterations

Scientifically accepted conceptions

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I also wish to thank all those who in diverse ways, contributed to make this thesis a success and to express my gratitude to my wife, Jemimah for her support, patience and encouragement.

DEDICATION

To my family for their encouragement and patience

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CHAPTER ONE

INTRODUCTION

This study sought to develop a teaching and learning material as part of the pedagogical content knowledge (PCK) for chemical formulae and chemical equations of inorganic compounds. This study was important because research conducted by Johnstone, Morrison and Sharp (1976); Gower (1977); Lazonby, Morris, and Waddington (1982) Suderji (1983); Anamuah-Mensah and Apafo (1986); Savoy (1988); Bello (1988); Hines (1990) and Baah (2009) as well as the chemistry Chief Examiners' reports of Senior High schools for 1994, 1995, 1999, 2001, 2003, 2004, 2005, 2008, 2009, 2010, 2011, 2012, 2013, 2014 and 2015 have revealed that students have difficulties on how to write correct chemical formulae and chemical equations. The study then used one group pre-test-post-test experimental design applied to two groups of students to develop a teaching and learning material as part of the pedagogical content knowledge for chemical formulae and chemical equations. Based on this, the study employed the cognitive psychological theories that lay emphasis on cognitive development and individual interaction with the environment (Piaget, 1952), social interaction (Vygotsky, 1978) and conceptual change (Posner, Strike, Hewson & Gertzog, 1982).

Background to the Study

This study sought to develop a teaching and learning material as part of the pedagogical content knowledge for chemical formulae and chemical equations. Shulman (1986) introduced the phrase pedagogical content knowledge (PCK) and this sparked a whole new wave of scholarly articles on teachers' knowledge of their subject matter and the importance of this knowledge for successful teaching. In Shulman's theoretical framework of teaching, teachers need to master two types of knowledge: (a) content, also known as "deep" knowledge of the subject itself, and (b) knowledge of the curricular development. Content knowledge encompasses what Bruner (as cited in Shulman, 1992) called the "structure of knowledge" the theories, principles, and concepts of a particular discipline. Especially important is content knowledge that deals with the teaching process, including the most useful forms of representing and communicating content and how students best learn the specific concepts and topics of a subject. "If beginning teachers are to be successful, they must wrestle simultaneously with issues of pedagogical content (or knowledge) as well as general pedagogy (or generic teaching principles)" (Grossman, as cited in Ornstein, Thomas, & Lasley, 2000).

Students (the teacher's audience) are another important element for the teacher to consider while using a pedagogical model. A skillful teacher figures out what students know and believe about a topic and how learners are likely to "hook into" new ideas. Teaching in ways that connect with students also requires an understanding of differences that may arise from culture, family experiences, developed intelligences, and approaches to learning. Teachers need to build a foundation of pedagogical learner knowledge (Grimmet & Mackinnon, 1992). To help all students learn, teachers need several kinds of knowledge about learning. They need to think about what it means to learn different kinds of material for different purposes and how to decide which kinds of learning are most necessary in different contexts. Teachers must be able to identify the strengths and weaknesses of different learners and must have the knowledge to work with students who have specific learning disabilities or needs. Teachers need to know about curriculum resources and technologies to connect their students with sources of information and knowledge that allow them to explore ideas, acquire and synthesize information, and frame and solve problems. Teachers need to know about collaboration, how to structure interactions among students so that more powerful shared learning can occur; how to collaborate with other teachers; and how to work with parents to learn more about their children and to shape supportive experiences at school and home (Shulman, 1992). Acquiring this sophisticated knowledge and developing a practice that is different from what teachers themselves experienced as students, requires learning opportunities for teachers that are more powerful than simply reading and talking about new pedagogical ideas (Ball & Cohen, 1996). Teachers learn best by studying, by doing and reflecting, by collaborating with other teachers, by looking closely at students and their work, and by sharing what they see.

This kind of learning cannot occur in college classrooms divorced from practice or in school classrooms divorced from knowledge about how to interpret practice (Miller & Silvernail, 1994). Good settings for teacher learning in both colleges and schools provide lots of opportunities for research and inquiry, for trying and testing, for talking about and evaluating the results of learning and teaching. The combination of theory and practice (Miller & Silvernail, 1994) occurs most productively when questions arise in the context of real students and work in progress and where research and disciplined inquiry are also at hand.

Pedagogical content knowledge (PCK) has been identified as an important component of teachers' professional knowledge. PCK is defined as the blend of knowledge of content to be taught and knowledge of pedagogy that results in teachers' understanding of how the teaching content can be best organised, adapted, and presented to students of diverse abilities and interests (Shulman, 1987). Shulman (1986) defined pedagogical content knowledge as: "the most useful forms of content representation, the most powerful analogies, illustrations, examples, explanation, and demonstrations in a word, the ways of representing and formulating the subject that makes it comprehensible to others" (p.9).

PCK can be understood as the knowledge that can be used by teachers to transform their subject matter knowledge into teachable content knowledge (Geddis, Onslow, Beynon, & Oesch, 1993). Several international studies on PCK have been conducted (Adams & Krockover, 1997; Carlsen, 1993; Grossman, 1990; Magnusson, Krajcik, & Borko, 1999; Marks, 1990) which have identified the components of PCK. These components include: 1) knowledge and beliefs of teaching objectives, 2) knowledge and beliefs of the science curriculum, 3) knowledge and beliefs of teaching strategies, 4) knowledge and beliefs of students' understanding of science, and 5) knowledge and beliefs of learning assessment. Research seeking to understand PCK has also revealed sources that contribute to the development of PCK.

The first source is disciplinary study. This is the study of the knowledge and skills that are to be learned by school students. Shulman (1987) identified this source as 'scholarship in content discipline'. Meanwhile, Grossman (1990) labels this source as 'disciplinary background'. Disciplinary study provides a basis for the knowledge of content, syntactic structure, as well as substantive structure understandings. According to Grossman, disciplinary understanding influences teachers' decisions about the selection of the relative importance of particular content and the selection and sequencing of the content. The influence of disciplinary study at college on teachers' PCK is revealed in a study conducted by Adams and Krockover (1997) who studied the origins of beginning science teacher cognitions. In the research, they found that teachers relied on their curricular knowledge based on disciplinary study, which included college coursework, high school coursework, and college and high school textbooks.

The second source of PCK is educational study. Educational study includes study about teaching, learning, student development, and philosophical and ethical foundations of education. This study called as 'formal educational scholarship' by Shulman (1987), and as 'professional coursework' by Grossman (1990). While subject matter knowledge can be acquired from disciplinary study, educational study provides a basis for teachers' knowledge and skills of teaching strategies, classroom management, and modes of assessment.

The tension between these two sources, disciplinary study and educational study, is one of the major debates in teacher education research. Some argue that the most important part of teacher education is disciplinary study. On the other hand researchers believe that educational study is not less important than disciplinary study. Both disciplinary and educational studies are equally important. The existing teacher education programmes reflect the result of this debate. The third source of PCK is teacher experiences. Shulman (1987) pointed out the importance of experience on the development of teachers' PCK. He maintained that the 'wisdom of practice' provide reflective rationalization for the teachers. A knowledge base for teaching is not fixed or final. Teachers should continuously reconstruct and develop an understanding of teaching - based on teaching experience through a reflective process. Comparative analysis between novice and expert teachers indicates that expert teachers have more understanding about PCK than their novice counterparts. This finding leads to the conclusion of the importance of experience in the development of PCK. The experience includes those received during the years of education. Grossman (1990) identifies this experience as apprenticeship observation. Apprenticeship observation influences teachers in deciding which teaching strategies, learning outcome expectations, and curricular knowledge are valid. In other words, teacher training should demonstrate through its practice, the principles and techniques to be employed by teachers.

The contribution of teacher preparation programmes to the development of PCK is revealed in the research conducted by Adams and Krockover (1997) who found that instructional strategies used by teachers are inspired by subject matter courses at their college experiences as students. The study has also identified sources that contribute to the development of teachers' understanding of PCK.

These sources include: learning and teaching experiences in various level of education. Adam and Krockover (1997) identified that one of the sources of teachers' understanding of PCK was a disciplinary study at the students' teacher training college. Hence, the content taught and the teaching strategies used by the lecturers to teach disciplinary subjects in the university are factors that could, and should, facilitate prospective teachers' understanding of PCK. Shulman (1986, 1987) proposed that teachers' professional knowledge is comprised of a variety of categories, with one of these categories being PCK. Shulman conceptualized PCK as including "the most powerful analogies, illustrations, examples, explanations, and demonstrations in a word, the ways of representing and formulating the subject that makes it comprehensible for others" (1986, p.9). It was "the category [of teacher knowledge] most likely to distinguish the understanding of the content specialist from that of the pedagogue"(1987, p. 8). Shulman claimed that teachers needed strong PCK to be the best possible teachers. He asserted that teachers had a unique way of looking at practice and his intrigue with the manner in which they did so encouraged an examination of teachers' pedagogical thinking in ways that, it was anticipated, would reveal what teachers must know to best teach their content to students.

Shulman's notion of PCK created many and varied responses and has been interpreted in different ways (Bromme, 1995; Geddis, Onslow, Beynon, & Oesch, 1993; Gess-Newsome & Lederman, 1999; Grimmett & MacKinnon, 1992; Grossman, 1990). However, regardless of interpretation, PCK has become an accepted academic construct. A common view of PCK is that it is bound up and recognizable in a teacher's approach to teaching particular content. PCK is thought to be the amalgam of a teacher's pedagogy and understanding of content such that it influences his teaching in ways that will best engender students' learning for understanding.

Shulman's (1986, 1987) approach to thinking about teachers' knowledge led to a shift in understanding and a new valuing of teachers' work such that research began to focus on understanding teaching from the teacher's perspective rather than the previous approach that focused on evaluation and labeling of teachers and teaching behaviors. From this new perspective, researchers began to find ways of examining what teachers knew (Clandinin & Connelly, 1995; Cochran-Smith & Lytle, 1990).

As Van Driel, Verloop, and De Vos (1998) noted, although the research community embraced the notion of PCK, the stark reality is that there are few science topic–specific examples in the literature to illuminate this important aspect of teachers' professional knowledge. This is perhaps not so surprising, because, as Carter (1993) suggested, teachers' knowledge is elusive, and there is no language or structure to adequately discuss such knowledge.

The need for PCK for teaching chemical formulae and chemical equations has become necessary because chemistry teachers have used several teaching methods in the past to teach the two concepts yet students have problems grasping the concepts. For instance reports of chemistry Chief Examiners' (CE) for Senior High Schools available at the West Africa Examinations Council (WAEC) for the years 1994, 1995, 1999, 2001, 2005, 2008, 2009, 2010, 2011, 2012, 2013, 2014 and 2015 attest to the fact that Senior High School students have difficulties in writing correct chemical formulae and chemical equations. Furthermore, research conducted by Baah (2009) to investigate Senior High School students' understanding of chemical formulae and chemical equations confirmed the difficulties of students as reported by the chemistry Chief Examiner.

The need for useful games which can help students to easily grasp the two topics has therefore become necessary. An appropriate game on writing of chemical formulae can help students to easily grasp the concept and also aid in recall of those formulae.

Statement of the Problem

Studies have shown that the ability required to write chemical equations correctly is not a simple one (Gower, 1977; Suderji, 1983 ; Savoy, 1988). It is one that requires a functional understanding of the requisite subordinate concepts of atoms and atomicity, molecules and molecular formula, atomic structure and bonding, valency, use of brackets, radicals, subscripts and coefficient and molar ratio (Savoy, 1988). The findings from research conducted by Lazonby, Morris, and Waddington (1982) and Bello (1988) have shown that students' persistent difficulties in solving stoichiometric problems are partly associated with their inability to write chemical formulae and represent chemical equations correctly.

Studies conducted by Savoy (1988) and Hines (1990) have reported that many students learning chemistry have great difficulties, both in acquiring and using the needed ability to balance chemical equations. The study by Hines (1990), for example, showed that chemistry students in Botswana had a poor understanding of chemical equations. A similar study conducted by Johnstone, Morrison and Sharp (1976) in Scotland revealed that students in Senior High Schools are less confident about writing chemical equations and carrying out calculations based on them. A study conducted by Anamuah – Mensah and Apafo (1986) revealed that students in Ghanaian Senior High Schools have difficulties in learning certain chemical concepts such as chemical combination. From the study, 66% of respondents who took part in the study indicated that the topic chemical combination was either difficult to grasp or never grasped.

Chief Examiners' (CE) reports of the West African Examinations Council (WAEC) reveal that students have difficulty in writing chemical formulae and chemical equations. In 1994, the CE report indicated that most candidates could not write balanced chemical equation in the chemistry paper at the Senior Secondary School Certificate Examination (SSSCE). In the chemistry practical examination of the same year, the CE stated that Sodium trioxocarbonate (IV) and Sodium hydrogen trioxocarbonate (IV) were badly written as NACO and NA_2HCO_3 respectively. In 1995, the CE report stated that many candidates had problems with writing chemical equations and the systematic naming of inorganic compounds. In 1999, the CE report indicated that students were unable to write equations for reactions between Bronsted Lowry bases and concentrated HCl. The report also stated that students were unable to give the IUPAC names of some given compounds. In 2001, the CE report said that writing of chemical formulae and writing of ionic equations was poorly handled by candidates. A summary of candidates' weaknesses of the 2003 CE report shows that candidates could not balance chemical equations. The 2004 chemistry theory paper required candidates to write a balanced chemical equation for the production of oxygen when $KClO_3$ is heated and then calculate the volume of dry oxygen gas evolved. The examiners' CE report on the above question was that candidates had problems writing the equation correctly and hence could not get the correct mole ratio. Also the 2005, CE report indicated that candidates had problems writing chemical equations and formulae of substances. In the summary of candidates' weaknesses of chemistry 2 (theory) paper of the 2008 WASSCE, the Chemistry Chief Examiner lamented that most of the candidates had problems writing chemical equations. The report went further to state that in question 5(c) of the same paper, students were requested to write balanced chemical equation for the thermal decomposition of each of the following compounds:

(i) Li_2CO_3

(ii) K_2CO_3

(iii) $LiNO_3$

The Chief Examiner's comment was that the above question posed problems to most candidates. Also in the 2009 examiner's report, question 4(d) of the chemistry 2 (theory), paper requested the students to write a balanced chemical equation for the reaction between sodium and water and then use the equation to determine the volume of the gas produced at STP. The chemistry chief examiner's report on this question was that most candidates could not write the correct equation between sodium and water. In 2013, the Q3(a)(ii) of the chemistry 2 paper requested students to write chemical equations to show that aluminium oxide is amphoteric. According to the Chief Examiner, majority of the candidates could not write the equation of Al_2O_3 with a base.

In a study conducted by Baah (2009) to investigate Senior High School students' understanding of chemical formulae and chemical equations, the schools that took part in the study were categorized into well-endowed and less-endowed Senior High Schools. Participants who have all been instructed with the traditional didactic teaching method of how to write chemical formulae and chemical equations took achievement tests in chemical formulae and chemical equations. Out of 205 students from well-endowed schools, only 31 (15.1%) could write the formula for Copper (II) tetraoxophosphate (V) and out of 129 students from less–endowed schools only 6 (4.7%) could do same. Also, for the compound Silver nitride, only 11.2% and 3.1% of the students from well-endowed and less endowed schools respectively could write the correct formula of the compound.

For the compound Potassium trioxochlorate (V), only 23.9% and 3.9% of the students from well-endowed and less endowed schools respectively could determine the ions that formed the compound. For the compound aluminium oxide, only 14.6% of the well-endowed students and 7.0% of less-endowed students could determine correctly the subscripts of ions that formed the compound. It came out of the study that the major problem that impeded students' effort to write correct chemical formulae was their lack of knowledge of valency and the role it play in the writing of chemical formulae.

Regarding the writing of chemical equations, only 24.4% and 5.4% of the students from well-endowed and less endowed schools respectively could predict correctly the products of the acid-base reaction between $Ca(OH)_2$ and H_3PO_4. This is a clear manifestation of the problem students have in determining ions of ionic compounds and their lack of knowledge of valency and its role in formulae writing. Regarding translation of statement reactions into chemical equations in symbols, only 25.4% and 7.0% of the students from well-endowed and less endowed schools respectively could translate correctly the statement reaction between Potassium hydroxide and tetraoxophosphate (V) acid to form potassium tetraoxophosphate (V) and water. Also for the statement reaction between Barium chloride and potassium tetraoxosulphate (VI) to form barium tetraoxosulphate (VI) and potassium chloride, only 30.5% of all the students who took part in the study could correctly translate the above reaction into chemical equation in symbols. This inability was largely due to students' difficulties in writing the formulae of the individual compounds in the equation.

Hence the study revealed the following difficulties on the part of Senior High School students in writing chemical formulae from IUPAC names of compounds:

(a) Lack of understanding of the meaning of Roman numerals that are put in brackets of IUPAC names.

(b) Problem with what valencies are and lack of understanding of the role they play in writing of chemical formulae.

(c) Problem with writing the correct formula of some radicals and some ions

(d) Difficulty in determining the number of atoms of each element in compounds

(e) Difficulty in determining the ions (cations and anions) that form ionic compounds.

With regard to the writing of chemical equations, the study identified that students' inability to predict correct products of reactions was due to their inability to write the correct formulae of the reaction products. There is therefore a strong need of a teaching method that could address students' misunderstanding of these two topics.

Purpose of the Study

The purpose of this study was to develop a teaching and learning material as part of the pedagogical content knowledge for chemical formulae and chemical equations of inorganic compounds. This was achieved by pre-testing an SHS 1 science class and an SHS 2 science class to determine their initial difficulties and conceptions after which they were taken through series of iterations and followed through to see how their conceptions of the two topics changed as they went through the iterations to develop the teaching and learning material. The study also sought the views of SHS chemistry teachers about issues concerning the teaching and learning of chemical formulae and chemical equations of inorganic compounds and highlights of the teachers' views were factored into the development of the teaching and learning material. The study sought to determined whether there was any significant difference between the pre-test and the final post-test results of both SHS 1 and 2 science students used to develop the teaching and learning material and to find how much they have gained from the pre-test to the final post-test. Finally, the study validated the teaching and learning material developed by pre-testing other SHS 1 students from the accessible population using the same pre-test items as before, taught them with the already developed teaching and learning material and they were post-tested.

Research Questions

The following research questions were formulated to guide the study:

1. What views do SHS chemistry teachers hold about the teaching and learning of chemical formulae and chemical equations at the SHS level?
2. What initial difficulties do SHS 1A and SHS 2A science students have on the writing of :

   (i) chemical formulae and

   (ii) chemical equations?
3. What is the performance of SHS 1A and SHS 2A science students in the various post-tests during development of the teaching and learning material?
4. What is the performance of the validation SHS 1 science students in the pre-test and post-test during validation of the teaching and learning material already developed?

Hypotheses

The following hypotheses were also tested in the study:

1. H_O: There is no statistically significant difference in the degree of changes in conceptions of SHS1A science students between their pre-test and post-test 3 on writing of chemical formulae during development of the teaching and learning material in this study.

   H_1: The degree of changes in conceptions of SHS 1A science students on writing of chemical formulae in post-test 3 during development of the teaching and learning material will be significantly better than their conceptions in the pre-test.

2. H_O: There is no statistically significant difference in the degree of changes in conceptions of SHS1A science students between their pre-test and post-test 3 on writing of chemical equations during development of the teaching and learning material in this study.

   H_1: The degree of changes in conceptions of SHS 1A science students on writing of chemical equations in post-test 3 during development of the teaching and learning material will be significantly better than their conceptions in the pre-test.

3. H_O: There is no statistically significant difference in the degree of changes in conceptions of SHS 2A science students between their pre-test and post-test 3 on writing of chemical formulae during development of the teaching and learning material in this study.

H_1: The degree of changes in conceptions of SHS 2A science students on writing of chemical formulae in post-test 3 during development of the teaching and learning material will be significantly better than their conceptions in the pre-test.

4. H_O: There is no statistically significant difference in the degree of changes in conceptions of SHS 2A science students between their pre-test and post-test 3 on writing of chemical equations during development of the teaching and learning material in this study.

H_1: The degree of changes in conceptions of SHS 2A science students on writing of chemical equations in post-test 3 during development of the teaching and learning material will be significantly better than their conceptions in the pre-test.

5. H_O: There is no statistically significant difference in the degree of changes in conceptions of validation SHS 1 science students between their pre-test and post-test on writing of chemical formulae during validation of the teaching and learning material developed.

H_1: The degree of changes in conceptions of validation SHS 1 science students on writing of chemical formulae in their post-test during validation of the teaching and learning material will be significantly better than their conceptions in the pre-test.

6. H_O: There is no statistically significant difference in the degree of changes in conceptions of validation SHS 1 science students between their pre-test and post-test on writing of chemical equations during validation of the teaching and learning material developed.

H_1: The degree of changes in conceptions of validation SHS 1 science students on writing of chemical equations in their post-test during validation of the teaching and learning material will be significantly better than their conceptions in the pre-test.

7. H_O: There is no statistically significant difference between the pre-test and the post-test 3 results in the writing of chemical formulae for SHS1A science students who were taught with the teaching and learning material developed in this study.

H_1: The post-test 3 chemical formulae results of SHS 1A science students taught with the teaching and learning material developed in this study will significantly be higher than their pre-test results.

8. H_O: There is no statistically significant difference between the pre-test and the post-test 3 chemical formulae results of SHS 2A science students who were taught with the teaching and learning material developed in this study.

   H_1: The post-test 3 chemical formulae results of SHS 2A science students taught with the teaching and learning material developed in this study will be significantly higher than their pre-test results.

9. H_O: There is no statistically significant difference between the pre-test and the post-test 3 chemical equations results of SHS 1A science students who were taught with the teaching and learning material developed in this study.

   H_1: The post-test 3 chemical equations results of SHS 1A science students taught with the teaching and learning material developed in this study will be significantly higher than their pre-test results.

10. H_O: There is no statistically significant difference between the pre-test and the post-test 3 chemical equations results of SHS 2A science students who were taught with the teaching and learning material developed in this study.

    H_1: The post-test 3 chemical equations results of SHS 2A science students taught with the teaching and learning material developed in this study will be significantly higher than their pre-test results.

11. H_O: There is no statistically significant difference between the pre-test and the post-test chemical formulae results of the validation SHS1 science students who were taught with the teaching and learning material already developed in this study.

H_1: The post-test chemical formulae results of the validation SHS 1 science students taught with the teaching and learning material already developed in this study will be significantly higher than their pre-test results they had before they were taught.

12. H_O: There is no statistically significant difference between the pre-test and the post-test chemical equations results of the validation SHS 1 science students who were taught with the teaching and learning material already developed in this study.

H_1: The post-test chemical equations results of the validation SHS 1 science students taught with the teaching and learning material already developed in this study will be significantly higher than their pre-test results they had before they were taught.

Significance of the Study

The teaching and learning material developed in this study could be of immense benefit to chemistry teachers as it would furnish them another strategy to use in the teaching of chemical formulae and chemical equations. The teaching and learning material developed in this study is a teacher support material and hence could be of help to the Ghana Education Service as the material could be incorporated into the chemistry and integrated science curricula at both junior and senior high school levels. Both science and non science students could benefit from the teaching and learning material developed as it could help them in understanding and recall of chemical formulae and chemical equations. Finally, the study could buttress the advocacy by science education policy makers that science teaching must be innovative by contextualization because it enhances learning.

Delimitation

Only one SHS 1 science class and one SHS 2 science class were used in this study. The two classes were drawn from two schools of 26 SHS 1 and SHS 2 science classes in the Cape Coast Metropolis. The reason for using these two science classes was that the researcher was interested in using a class that had been taught and a class that had not been taught the two topics at the time of the study. This was done to see how the teaching and learning material developed in this study could be used to teach the two classes. The study also focused on only combination, displacement and metathesis reactions and did not cover decomposition and combustion reactions. Chemical formulae covered only the formulae of inorganic compounds as the teaching and learning material developed in this study was suitable for ionic species.

Limitations

One limitation in this study was the restriction imposed on the data because of the decision to focus on only schools, which offer the elective science programme. Also, the focus on only two classes out of a total of twenty-six classes from the two schools selected places a limitation on the study and will affect the generalizability of the findings of the study in some respects. This was due to limited financial resources and time at the researcher's disposal.

Organisation of the Thesis

Chapter one is basically introduction which includes background to the thesis, statement of the problem, research questions and hypotheses raised to guide the study, significance of the study, delimitation and limitations. The thesis has four additional chapters, which have been logically arranged to show how the teaching and learning material was developed. Chapter two of the thesis is devoted to a review of the relevant literature on issues relating to the study namely, theories of learning, various methods of teaching and learning used in the past and present, teacher support materials, students' conceptual understanding of chemical representations and importance of pedagogical content knowledge among others.

Chapter three discusses the research methodology for the study. It describes the type of study and design in detail, and the rationale for the design. The strengths and weaknesses of the design are also discussed. Issues relating to population and sampling, instruments, data collection procedure, and data analysis are also discussed in detail. In chapter four, the results of the study are presented and discussed with reference to the research questions. In Chapter five, an overview of the research problem and methodology are given. A summary of the key findings, implications and conclusions relating to the findings are also discussed. In addition, the issues unearthed for possible future research are presented.

CHAPTER TWO

LITERATURE REVIEW

This chapter reviews and discusses literature related to the study. The review focuses on developmental research, theories of learning, various methods of teaching and learning used in the past and present, teacher support materials, students' conceptual understanding of chemical representations, importance of subject matter knowledge, pedagogical content knowledge, chemical formulae and chemical equations in the junior and senior high school science curricula, Chief Examiners' Reports on performance of students in chemical formulae and chemical equations in chemistry examinations at the SHS level and studies on students' understanding and difficulties of writing chemical formulae and chemical equations. The chapter is concluded with summary and implication of the literature reviewed.

Developmental Research

Developmental research (the design of this study) is an extended action research. A basic motive of developmental research stems from the experience that 'traditional' research approaches (e.g. experiments, surveys, correlational analyses), with their focus on descriptive knowledge, hardly provide prescriptions with useful solutions for a variety of design and development problems in education. They contribute more to educational improvement processes with a noticeable impact. Moreover, more direct interaction with practice might offer the researchers valuable incentives for sharpening their theoretical insights and transforming their descriptive knowledge in design principles. Also, there is a distinct scientific interest at stake. The major goal of such research is to inform the decision making process during the development of a product or program in order to improve the product or program being developed and the developers' capabilities to create things of this kind in future situations.

Van den Akker and Plomp (1993) defined 'development research' by its twofold purpose: (i) supporting the development of prototypical products (including providing empirical evidence for their effectiveness), and (ii) generating methodological directions for the design and evaluation of such products. In this approach, the scientific contribution (knowledge growth) is seen as equally important as the practical contribution (product improvement).

According to Richey and Nelson (1996) developmental research is aimed at improving the processes of instructional design, development, and evaluation based on either situation-specific problem solving or generalized inquiry procedures" (p.1213). They make a clear distinction between performing a process and studying that process. In the latter instance, these studies often have a reconstructive nature.

Also in the broad sub-domain of learning and instruction, pleas for development research are increasingly made. Referring to earlier proposals of Brown (1992) and Collins (1992) to invest more in 'design experiments', Greeno, Collins and Resnick (1996) underline a significant shift in the relationship between theoretical and practical work in educational psychology. They highlight the "kind of research that includes developmental work in designing learning environments, formulating curricula, and assessing achievements of cognition and learning and, simultaneously, on efforts to contribute to fundamental scientific understanding" (p.41). Researchers should not only concentrate on the question of whether a theory yields coherent and accurate predictions, but also ask whether it works: do the theoretical concepts and principles inform practices in productive ways. In the same vein, Reigeluth and Frick (1999) argue for 'formative research', referred to as "a kind of developmental research that is intended to improve design theory for designing instructional practices or processes" (p. 633).

In the area of teacher education, development research contributes to teachers' professional learning and/or bringing about change in a specific educational setting (Elliott, 1991; Hollingsworth, 1997). In the area of didactics the emphasis tends to be on 'developmental research' as an interactive, cyclic process of development and research in which theoretical ideas of the designer feed the development of products that are tested in classroom settings, eventually leading to theoretically and empirically founded products, learning processes of the developers, and (local) instructional theories.

Development research is often initiated for complex, innovative tasks for which only very few validated principles are available to structure and support the design and development activities. Since in those situations the image and impact of the intervention to be developed is often still unclear, the research focuses on realizing limited but promising examples of those interventions. The aim is not to elaborate and implement complete interventions, but to come to (successive) prototypes that increasingly meet the innovative aspirations and requirements. The process is often cyclic or spiral: analysis, design, evaluation and revision activities are iterated until a satisfying balance between ideals and realization has been achieved.

More than most other research approaches, development research aims at making both practical and scientific contributions. In the search for innovative 'solutions' for educational problems, interaction with practitioners (in various professional roles: teachers, policy makers, developers, and the like) is essential. The ultimate aim is not to test whether theory, when applied to practice, is a good predictor of events. The interrelation between theory and practice is more complex and dynamic: is it possible to create a practical and effective intervention for an existing problem or intended change in the real world? The innovative challenge is usually quite substantial; otherwise the research would not be initiated at all. Interaction with practitioners is needed to gradually clarify both the problem at stake and the characteristics of its potential solution. An iterative process of 'successive approximation' or 'evolutionary prototyping' of the 'ideal' intervention is desirable. Direct application of theory is not sufficient to solve those complicated problems. One might state that a more 'constructivist' development approach is preferable: researchers and practitioners cooperatively construct workable interventions and articulate principles that underpin the effects of those interventions.

Formative evaluation holds a prominent place in development research, especially in formative research. The main reason for this central role is that formative evaluation provides the information that feeds the cyclic learning process of developers during the subsequent loops of a design and development trajectory. It is most useful when fully integrated in a cycle of analysis, design, evaluation, revision, et cetera, and when contributing to improvement of the intervention.

Formative evaluation within development research should not only concentrate on locating shortcomings of the intervention in its current (draft) version, but especially generate suggestions in how to improve those weak points. Richness of information, notably salience and meaningfulness of suggestions in how to make an intervention stronger, is therefore more productive than standardization of methods to collect and analyze data. Also, efficiency of procedures is crucial.

The lower the costs in time and energy for data collection, processing, analysis and communication, the bigger the chances on actual use and impact on the development process. For example, samples of respondents and situations for data collection will usually be relatively small and purposive compared to sampling procedures for other research purposes. The added value of getting 'productive' information from more sources tends to decrease, because the opportunities for 'rich' data collection methods (such as interviews and observations) are limited with big numbers. To avoid an overdose of uncertainty in data interpretation, often triangulation (of methods, instruments, sources, and sites) is applied. These arguments especially hold true for early stages of formative evaluation, when the intervention is still poorly crystallized. The basic contribution of formative evaluation is to quality improvement of the intervention under development. Quality, however, is an abstract concept that requires specification. During development processes, the emphasis in criteria for quality usually shifts from validity, to practicality, to effectiveness. Validity refers to the extent that the design of the intervention is based on state-of-the-art knowledge ('content validity') and that the various components of the intervention are consistently linked to each other ('construct validity'). Practicality refers to the extent that users (and other experts) consider the intervention as appealing and usable in 'normal' conditions. Effectiveness refers to the extent that the experiences and outcomes with the intervention are consistent with the intended aims.

A challenging trend for designers is the increasing prominence of prototyping approaches. Various questions arise: What does (rapid/evolutionary) prototyping imply for efficiency of the development process? Will it affect the balance between creative and systematic features of the approach? Does it reduce the relevance of preliminary investigations? To what extent does it influence the relationship between methodology (as prescribed in literature) and actual design activities in professional practices (can 'theory' keep up with 'practice', or will the gap even widen)? In relation to this trend: will the many emerging technological tools and environments for learning, communication, designing and performance support strongly change development approaches and outcomes? Will they reduce the distance between design, delivery, and utilization of educational interventions? Many challenges are also apparent with respect to evaluation methodology. What are appropriate tactics for increasing the information richness and efficiency of data collection procedures and instruments? How may the linkages between data collection, processing, and analysis be optimized? How can the communication about evaluation findings and the subsequent utilization for improvement of interventions be furthered? What are the most relevant indicators of quality, success and impact of interventions? What are promising approaches to further the generalizibility of research findings? How can the utilization of evaluation findings to design tasks in other settings be facilitated?

Developmental research has the efficacy of generating interest in students that will enhance their performance in science and also help the teachers to enhance their teaching strategy. Richey and Nelson (as cited in Tilya, 2003) describe developmental research in education as the production of knowledge with the aim of improving the process of design, development and evaluation of educational products. From the perspective of curriculum, van den Akker and Plomp (1993) specified two purposes of developmental research as: (a) supporting the development of prototypes of the educational products; and (b) generating methodological directions for the design and evaluation of such educational products. From these purposes Tilya (2003) affirmed that developmental research contributes to two main aspects: product improvement and knowledge growth. Product improvement seeks to develop a high quality educational product, and knowledge growth is reflected in the design principles. Developmental research is usually chosen when the study looks promising in generating information that provides useful solutions for a variety of design problems in often, unclear contexts (van den Akker, 1999). Therefore, developmental research is action research. Developmental research provides flexibility in developing an intervention stage-by-stage within the problem context. Hence it provides good opportunity for understanding local implementation conditions and the difficulties teachers experience in the implementation process. The developmental research approach is very relevant and appropriate for its potential impact on the professional development of participants, and its capacity to build on that development (van den Akker 2002). Studies involving the use of the developmental research design have shown great promise and results (Kitta, 2004; Mckenney, 2001; Ottevanger, 2001; Stronkhorst, 2001; Thijs, 1999; Tilya, 2003). Developmental research (i.e. action research) approach to issues is seen as a means to influence educational practice by experimenting with promising interventions and seeing whether, in real classroom settings they work or yield fruitful outcomes.

Theories of Learning

Cobern (1996), proposed that curriculum developers could incorporate innovative knowledge in science curricula. This type of curricula would offer the teachers the opportunity to utilize innovative practices in their science lessons based on learning theories, some of which are: active learning; social learning; social development; and situated learning. A combination of these learning theories is found relevant for adoption in this study.

Active Learning

The approach emphasizes a variety of different types of methods that transforms the role of teachers from givers of information to facilitators of student learning; when a person shifts the role he already knows, largely it determines what new information he attends to, how he organizes and represents the new information (Alexander & Murphy, 2000). Successful students are actively involved in their own learning; they monitor their thinking, think about their learning, and assume responsibility for their own learning (Lambert & McCombs, 2000). Learning is a social process and how actively engaged students are in the learning process positively or negatively influences how much and what the students learn (Lambert & McCombs, 2000). The approach offered the learner the opportunity to synthesize his or her own knowledge through social and material interaction in the learner's environment. Learner-centered teaching is an approach to teaching that is increasingly being encouraged in higher education. Learner-centered teachers do not employ a single teaching method. Thus this approach emphasizes a variety of different types of methods that shifts the role of the instructors from givers of information to facilitating student learning. Learner-centered teaching places the emphasis on the person who is doing the learning (Weimer, 2002). Learner-centered teaching focuses on the process of learning (Blumberg, 2004). Strong, research evidence exists to support the implementation of learner-centered approaches instead of teacher-centered approaches. An advantage of Learner-centered teaching over teacher-centered teaching is that schools attain higher rates of student retention and have better prepared graduates than those students who were more traditionally trained that is, those taught with teacher-centered approaches to learning (Matlin, 2002; Sternberg & Grigorenko, 2002). Finally, studies that compared students in lecture and active learning courses show that there are significantly more learning gains in the active learning courses (Springer, Stanne & Donovan, 1999).

Hence development of pedagogical content knowledge for teaching is very well supported by this learning theory.

Social Learning

The social learning theory of Bandura (1977), for example, states in part that most human behaviour is learned by observation through modeling. It further states that from observing others one develops the idea of how new behaviours are performed and later what is learned serves as a guide for future learning. This theory supports learning by apprenticeship and therefore has an application in this study.

Social Development

Vygotsky (1978) posited that, social interaction plays a fundamental role in the development of cognition. His social learning theory states that: every function in the child's cultural development appears twice:

> first on the social level and later, on the individual level: first between people (inter-psychological) and then inside the child (intra-psychological). This applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher functions originate as actual relationships between individuals (p. 57).

According to Vygotsky (1978), the potential for cognitive development is limited to a specific time span which he calls zone of proximal development

(ZPD). He further indicated that cognitive development of a learner during ZPD depends on full social interaction by the learner with his or her learning environment. The implication of Vygotsky's ideas and theory in this study is that for concepts to be learnt effectively the learners must interact with their environment.

In the environment of learners, wood the material used to make the teacher support material in this study is common. Thus, it is expected that within a specific time frame of studying concepts in science within the social context, effective and meaningful learning should occur. Vygotsky's theory is seen to be a complement of Bandura's social learning theory and a key component of situated learning theory.

Situated Learning

Situated learning, otherwise known as situated cognition, is based on the concept that knowledge is contextually situated and it is fundamentally influenced by the activity, context and culture in which it is used (Lave & Wenger, 1990). A modifying concept emerging from research in situated learning is the idea that learning occurs through the sharing of purposeful, patterned activity (Lave & Wenger, 1991). As a consequence, Lave and Wenger see learning as an opportunity for one to increase one's participation in commonly experienced situations. Jonassen (1994) described situated learning as occurring when students work on tangible and realistic tasks that reflect the real world. If learners do not see the use of the knowledge acquired to their everyday life, then the knowledge appears irrelevant to them and they become less motivated and eventually lose interest in studying it. Thus, Jonassen aptly stated that a de-contextualized knowledge is inert. The implication of Lave and Wenger's situated learning is that if the students learn concepts associated with everyday activity in their environment; it will bring more meaning to them. Consequently, they will be encouraged to learn the concepts easily since they will see the social application of them. In support of Jonassen's situated learning, McLellan (1996) also stated that situated cognition involves adapting knowledge and thinking skills to solve unique problems.

Thus, the knowledge acquired by the students after going through the use of the teacher support material developed, can help solve their problems with writing of chemical formulae and chemical equations.

Situated cognition therefore, elaborates the fact that deliberate activity and situations are integral part of cognition and learning and that the provision of appropriate learning activity produces desirable results. Furthermore, by ignoring situated nature of cognition, the goal of education to provide usable and robust knowledge is defeated. Research findings show that learning activity that deliberately uses the social and physical context are producing more understanding of learning or cognition (Lave & Wenger, 1991).

It is this finding that influenced me to adopt and incorporate part of the social development learning theory in this study.

Various Methods of Teaching and Learning used in the Past and Present

Over the years, chemistry teachers have used several teaching methods to teach writing of chemical formulae and chemical equations. One of such methods is constructivism. Constructivism is a philosophy of learning founded on the premise that, by reflecting on our experiences, we construct our own understanding of the world we live in (Merriam, Caffarella, & Baumgartner, 2007). We generate our own rules and mental models, which we use to make sense of our experiences. The early development of constructivist theory can be attributed to the work of John Dewey, Lev Vygotsky, and Jean Piaget (Henson, 2003; Huang, 2002; Merriam et al., 2007; Proulx, 2006). Constructivism is learner-centered rather than teacher-centered (Proulx, 2006). Learning, therefore, is simply the process of adjusting our mental models to accommodate new experiences. Some of the advantages of learner-centered education put forward by Dewey include students' increased intellectual curiosity, creativity, drive, and leadership skills (Henson, 2003). Teachers who are committed to learner-centered education seek to challenge students within their abilities while providing encouragement and recognition of student success. Constructivist theory places the student at the center of the learning experience, and learner-centered education can be facilitated in a variety of ways (Henson, 2003; Spigner-Littles & Anderson, 1999). Students learn by doing; therefore, actively engaging students in experience-based learning is one key to the construction of new meaning (Merriam et al., 2007). In developing learning experiences that will have maximum benefit to students, the teacher should also be cognizant of the needs of individual learners. When planning for curriculum delivery, viewing the curriculum from the learner's perspective and from its relevance to the learner can facilitate learning experiences that will have maximum impact on students (Garmston, 1996; Spigner-Littles & Anderson, 1999).

Effective teaching will nurture the desire to learn and attempt to engage learners not only on an intellectual level, but also on an emotional level. To facilitate all of these conditions for maximum construction of meaning, teachers need to create a safe learning environment where individuals are free from fear and open to constructive learning, where learners feel welcomed, comfortable, and respected (Henson, 2003; Spigner-Littles & Anderson, 1999). Proulx (2006) revealed that the constructivist theory has several implications for educators. It encourages teachers to be cognizant of the fact that learners bring with them prior knowledge about topics they teach. Learners' prior knowledge deserves recognition and may be utilized in constructing new meaning. Learning from mistakes can be a key element of constructivist learning activities, as they provide opportunities for further learning and are a natural part of the learning process. In a constructivist learning environment, teachers should be open to learning from their students as the students engage in creative construction of new concepts. As students verbalize their newly constructed knowledge, they provide learning opportunities for others who are in the same learning environment; and, they also engage in revising, analyzing, and improving their own construction as they verbalize it to others. According to Hewson (1992), constructivist teaching strategies promote conceptual change in students by taking cognizant of their initial ideas before formal instruction. The term conceptual change which is widely used and often stands for constructivist ideas of learning in general denote that learning science usually involves fundamental restructuring of already existing or pre-instructional knowledge (Vosniadou, 1994). The first theory about conceptual change was proposed by Posner, Strike, Hewson, & Gertzog (1982) and two kinds of conceptual change were explained in this theory by using Piaget's two terms: assimilation and accommodation. In the first one, new concept is assimilated by the preconceptual structure and in the second one, conceptual structure is accommodated if a students' existing concept contradicts with the newly learnt concepts. Posner et al. (1982) asserted that accommodation depends on some conditions such as dissatisfaction of students with the existing concept, plausibility of new concept (believing it to be true), intelligibility of new concept (knowing what it means) and fruitfulness of new concept (finding it useful). According to Hewson (1992), if the new conception follows all the four conditions, learning proceeds without difficulty. However, science educators face several difficulties when they attempt to put into practice the four proposed conditions in order to promote conceptual change. Hewson and Hewson (1992) suggest that conceptual change can be seen as a change of status attributed to a particular conception. They stressed that while the student's alternate conception was losing its status, the new concept learnt gain its status and therefore it was understood, accepted and seen as useful. They also emphasized that conceptual change should not be seen as a situation in which students' existing conceptions are completely deleted or exchanged for the new concept.

There are many constructivist teaching strategies suggested to change and improve students understanding during teaching of concepts in science (Clement, 1987; Nussbaum & Novick, 1982). Scott, Asoko, & Driver (1992) identified two main groups of teaching approaches that promote conceptual change in students. The first group consists of strategies that are based on cognitive conflict and the resolution of the conflicting perspectives. Strategies which emphasize cognitive conflict and the resolution of such conflict by the learner may be seen to be derived from Piagetian view of learning in which learners' active participation in reorganizing their knowledge is central. Students are made conscious about their own opinions and then an opposite event or some activities that challenge their own opinions are given. Examples of such strategies are the predict-observe-explain (POE) developed by White and Gunstone (1992) and learning cycle developed by Karplus and Thier in 1967.

The second group consists of strategies which build on students' existing ideas and opinions and spread them through for example analogy or metaphor to a new domain. According to Scott et al. (1992), the strategies which build on learners' existing knowledge schemes, extending them to new domains, may be seen to place less emphasis on the role of accommodation by the learner and instead focus on the design of appropriate interventions by the teachers to provide 'scaffolding' for new ways of thinking. Strategies belonging to this group are generally referred to as bridging strategy. Küçüközer and Kocakülah (2008) asserted that in order to promote immediate conceptual change in students, it is recommended to use cognitive conflict and analogy strategies together most of the time.

Constructivism has an application in this study because students' learned by taking part in an activity. The study also promoted conceptual change in the students because the teacher support material developed helped the students to replace a misconception identified in Baah (2009) with a scientifically acceptable concept.

Another teaching method that has been used by chemistry teachers over the years is inquiry method. Inquiry education (sometimes known as the inquiry method) is a student-centered method of education focused on asking questions. Students are encouraged to ask questions which are meaningful to them, and which do not necessarily have easy answers; teachers are encouraged to avoid giving answers when this is possible, and in any case to avoid giving direct answers in favor of asking more questions. The method was advocated by Postman and Weingartner (1969) in their book: Teaching as a Subversive Activity. Postman and Weingartner suggest that inquiry teachers have the following characteristics (pp. 34–37):

1. They avoid telling students what they "ought to know".
2. They talk to students mostly by questioning, and especially by asking divergent questions.
3. They do not accept short, simple answers to questions.
4. They encourage students to interact directly with one another, and avoid judging what is said in student interactions.

5. They do not summarize students' discussion.
6. They do not plan the exact direction of their lessons in advance, and allow it to develop in response to students' interests.
7. Their lessons pose problems to students.
8. They gauge their success by change in students' inquiry behaviors

Inquiry-based learning is an instructional method developed during the discovery learning movement of the 1960s. It was developed in response to a perceived failure of more traditional forms of instruction, where students were required simply to memorize fact laden instructional materials (Bruner, 1961). Inquiry learning is a form of active learning, where progress is assessed by how well students develop experimental and analytical skills rather than how much knowledge they possess.

Banchi and Bell (2008) suggest that there are four levels of inquiry-based learning in science education: confirmation inquiry, structured inquiry, guided inquiry and open inquiry. With confirmation inquiry, students are provided with the question and procedure (method), and the results are known in advance. Confirmation inquiry is useful when a teacher's goal is to reinforce a previously introduced idea; to introduce students to the experience of conducting investigations; or to have students practice a specific inquiry skill, such as collecting and recording data. In structured inquiry, the question and procedure are still provided by the teacher; however, students generate an explanation supported by the evidence they have collected. In guided inquiry, the teacher provides students with only the research question, and students design the procedure (method) to test their question and the resulting explanations. Because this kind of inquiry is more involved than structured inquiry, it is most successful when students have had numerous opportunities to learn and practice different ways to plan experiments and record data. At the fourth and highest level of inquiry, open inquiry, students have the purest opportunities to act like scientists, deriving questions, designing and carrying out investigations, and communicating their results. This level requires the most scientific reasoning and greatest cognitive demand from students.

The inquiry approach is more focused on using and learning content as a means to develop information-processing and problem-solving skills. The system is more student centered, with the teacher as a facilitator of learning. There is more emphasis on "how we come to know" and less on "what we know." Students are more involved in the construction of knowledge through active involvement. The more interested and engaged students are by a subject or project, the easier it will be for them to construct in-depth knowledge of it. Learning becomes almost effortless when something fascinates students and reflects their interests and goals. Assessment is focused on determining the progress of skills development in addition to content understanding. Inquiry learning is concerned with in-school success, but it is equally concerned with preparation for life-long learning. Inquiry classrooms are open systems where students are encouraged to search and make use of resources beyond the classroom and the school. Teachers who use inquiry can use technology to connect students appropriately with local and world communities which are rich sources of learning and learning materials. They replace lesson plans with facilitated learning plans that account for slight deviations while still keeping an important learning outcome in focus. They meet on-target questions with, "How do you suggest we investigate that question?" Another issue regarding inquiry-based learning has to do with a misconception about when to do inquiry. Inquiry is not only done in laboratory or group work, it can also be done in lectures that provoke students to think and question.

Teachers often discount the fact that when they are giving talks or lectures to students, the students, if engaged, are applying listening and observing skills using their senses. If teachers focus more on "how we come to know" by presenting evidence and information and encouraging student questioning, then talks can even become powerful inquiry models for students. Collaborative meaning-making can take place through discourse. For example, when discussing the internal structure of the earth, a teacher will often give the students information about just the names and sizes of these earth layers, or the "what we know." But what really is important and intriguing for the student is the "how do we know?" about these structures. No one has been down there, and physical probes have only scratched the surface. To enhance inquiry learning, the teacher should explain that indirect scientific evidence, mainly the transmission and reflection of different kinds of earthquake waves, provides much of our understanding about the internal structure of the earth. This approach provides the student with the opportunity not only to learn the names and sizes of the structures but, more importantly, to ponder and question the nature of indirect scientific evidence as well. Thus, an inquiry approach can help students connect science with the scientific method. Students learn to apply the method to various fields of study while coming to understand their content.

Inquiry teaching method also has application in this study because in the development of the teacher support material, both the teacher and students asked each other a lot of questions. Secondly, the material developed is aimed at helping students to develop problem-solving skills.

In role play as another teaching method, there are two different kinds. One kind involves having students act as if they were components of a physical or biological system. For example, you might have three students act as Oxygen and Magnesium. First, two students hold hands. They are an oxygen molecule. Then a spark comes along, to ignite the student who is acting as magnesium. Magnesium then takes one of the oxygen atoms, and the other oxygen atom is alone. You have had your students demonstrate a chemical reaction. A biology example would be to have some students act as blood cells, and to move to different locations in the classroom, where students acting as different body organs give or take from the blood. The blood would attach to oxygen in the lungs, attach to food in the intestines etc. and trade oxygen for carbon dioxide at the cells, etc. The other kind of role play involves an ethical issue. Students act as humans in a situation where a decision must be made. Different students are given brief descriptions of which they are and may be a description of their feelings about the issue. Then the students act out their roles and make a decision about the issue. Science-Technology-Society-Environment approach to science teaching should involve the students in discussing the impact of science and technology on society and the environment, and the impact of society and the environment on science and technology. Thus, there are many, many issues that we can create role plays for.

The second kind of role play is designed to foster the analysis of personal values. It should help students to develop strategies for solving personal and interpersonal problems. Hopefully, the students will also develop some empathy for others. Students should become more comfortable with expressing their opinions. Teachers ensure that other students do not judge the players harshly. The students are, after all, playing roles. Every role should be sympathetically presented, but we might not like what the particular character stands for. Although there could be limited number of students performing in each role play, the most effective role plays are ones in which all students are involved in some way. Role play was also used in this study where the teacher wanted the understanding of a concept to be so close to the students.

Concept attainment method involves students learning to classify a set of objects or events in a way that scientists classify. The students will be using the categories that scientists use, and will be attempting to determine the rationale behind the categories. The Concept Attainment Method has a high tolerance for ambiguity. This means that the students might seem to be following the wrong path, but eventually, they will come up with the expected answer. This method is used when the concept the students are expected to learn is fairly clear. The method is used instead of just telling the students or having them read, because students will learn the material much better when they figure it out for themselves. As the teacher's students learn more about the classification, he will also learn more about it. As well as learning the material better, and remembering it longer, the students will learn how to learn by using this method. Students should grow to become independent learners and critical thinkers. This method encourages certain of the Common Essential Learning. The most obvious are critical and creative thinking, communication, and of course, independent learning. Personal and social values and skills might be included if we allow students work in a positive way with their peers. As well, if the particular concept involves mathematical relationships, the students could use their numeracy. If the particular concept involves understanding a technology, technological literacy might also be addressed. Of course, as the students classify in the ways that scientists do, they will be learning a technique of science, and understanding techniques can be part of technological literacy. The commonest approach that teachers generally use in teaching science is the expository teaching (Ausubel, 1968). Odom and Kelly (2001) defined expository teaching as an organized lecture supplemented by slides, overheads, charts, and demonstrations to illustrate concepts and ideas. Linked to the expository teaching is Ausubel's theory of meaningful learning. According to Ausubel (1968), meaningful learning is the non-arbitrary, substantively relating new ideas or verbal propositions to cognitive structure. The learner consciously relates new ideas or verbal propositions to relevant aspects of his or her current knowledge structure in a conscious manner.

For meaningful learning to occur, the new ideas must have potential meaning and the learner must possess relevant concepts that can anchor new ideas.

Expository teaching approach brings about meaningful learning, which occurs by the process of subsumption when potentially meaningful propositions are subsumed under more inclusive ideas in existing cognitive structure. The new propositional meanings are hierarchically organized with respect to the level of abstraction, generality, and inclusiveness (Ausubel, 1968). The process of meaningful learning can be improved by expository teaching. During the teaching, the teacher graphically represents concepts in a hierarchically arranged structure and begins to progressively differentiate among concepts. Progressive differentiation refers to the learning process in which learners differentiate between concepts as they learn more about them. During the process of integrative reconciliation, the learner recognizes relationships between concepts and does not compartmentalize them (Novak, 1993).

Odom and Kelly (2001) reported a study they conducted to explore the effectiveness of the expository teaching as compared to the use of concept mapping and learning cycle to promote the conceptual understanding of diffusion and osmosis. Expository teaching was used to teach the two concepts to high school biology students in Kansas (the experimental group), the concept mapping and the learning cycle combined was used to teach the control group. The lessons for each group were the same. The timing of the presentation of the diffusion and osmosis content varied slightly from day to day. However, both groups received 6 days of instruction over the exact same content. A day after the teaching of each group a diagnostic test was administered to them without discussing the questions. Then seven days later the same test was administered to the two groups. It was found out that scores were not statistically significant among treatment groups the day after instruction (p > .05). The scores were statistically significant seven weeks after instruction which means that the approach could be feasible for teaching science in junior high schools in many areas in Ghana if overhead projectors, charts, and slides will be made available.

Expository method of teaching also has an application in this study because charts and demonstrations were used to teach and develop the teacher support material. Simulations are a useful teaching strategy for illustrating a complex and changing situation. Simulations are (necessarily) less complex than the situations they represent. In a simulation, the learner acts, the simulation reacts, the learner learns from this feedback. Examples of simulations: car and flight simulators, SIM City, Monopoly, mock elections, model UN. In each of these cases, the "game" involves rules, and the students must make decisions. Each decision a student makes affects the outcome of the game. For the students to learn what you intend for them to learn from the simulation, you must hold a discussion during and/or after the game. This is integral to the students' learning. There is so much we could have learned from playing Monopoly that went right through our heads because there was no discussion about what it all meant. The following are the phases of simulation. Phase One: Orientation. Here the teacher explains to his students what simulations are about and for and using some common games they play which are simulations as examples, they might start thinking about what real life complex situations the games model, and might learn something about them. Phase Two: The Simulation. Students participate in the game, playing their roles as assigned. The teacher is to coach and referee. He has to stay uninvolved, except when he notice that he can facilitate the educational opportunities the simulation presents. Phase Three: Debrief. Here the students are put into small groups. Three or four learning objectives are chosen for them for the simulation. The learning objectives are written as questions for discussion and one question should be about how the students think the simulation is like the real thing and how it is not like the real thing. Each small group of students is given one question to discuss. The students are told the time they have to discuss the questions. The teacher then selects a speaker and writes a summary of his discussion for the speaker to present to the class. In developing the teacher support material, for teaching chemical formulae and chemical equations, students interacted with the materials developed hence simulation also has an application in this study.

The application of a learning cycle to science teaching was proposed by Robert Karplus, Director of the Science Curriculum Improvement Study (SCIS) in 1970. He proposed a three phase cycle consisting of "preliminary exploration", "invention" and "discovery". In essence, Karplus believed that students need to first explore the concept to be learnt using concrete materials. The initial introduction of the concept was called invention phase. In this phase the teacher assumed an active role in helping the students use their exploration experiences to invent the concept. To Karplus, the discovery phase provided the student with the opportunity to verify, apply or further extend knowledge of the "invented" concept. Barman (1990) and Lawson, Abraham and Renner (1986) have proposed a three-phase learning cycle based on the work of Karplus. This learning cycle forms the foundation for sequencing science lessons as follows: Exploration, concept introduction, and concept application phases as described in Figure 1.

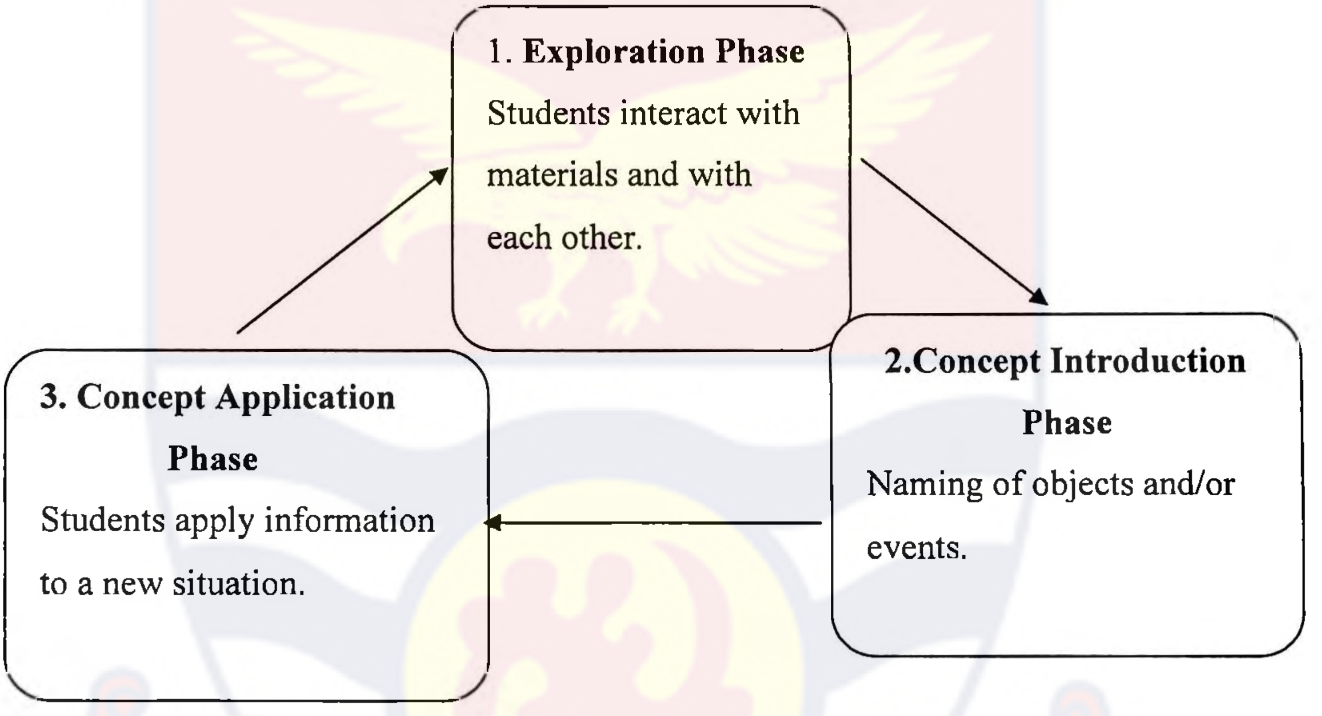


Figure 1: Learning Cycle Model

Source: Barman (1990) and Lawson, Abraham and Renner (1986).

Exploration phase

During this phase students explore a new concept or phenomenon with "minimal guidance." Students might make observations of and classify objects. They might be involved in "messing about" with batteries, bulbs and wires to find out how the light bulb works. Students might also perform experiments to gather data to test a hypothesis. In short, the exploration phase allows the students to examine "new ideas" and test them against their own ideas. Students are actively engaged in interacting with ideas, as well as their peers during the exploration phase. During this phase the teacher facilitates the work of the students by establishing reasons for exploring new ideas. The use of discrepant events, followed by interesting science activities is a way to get into the exploration phase. The teacher plays a facilitative role during this phase.

Introduction phase

During this phase the teacher assumes a more direct, active role and uses the students' exploratory activities as a means of introducing the scientists' view of the concept or theory that was investigated in the exploratory phase. During this phase students express their ideas about the concepts and ideas, and the teacher presents in very succinct ways, the meaning of the concepts and ideas from a scientific point of view. The teacher assumes the direct/interactive mode during this phase planning lessons along the guidelines presented in the direct/interactive section. The concept introduction phase is an intermediary step, and the teacher moves quickly to the next phase.

Concept application phase

The concept application phase is a student centered phase in which small teams of students engage in activities designed to apply and extend their knowledge of science concepts. The teacher designs activities that challenge the students to debate and defend their ideas. Activities in the concept application phase are problem-oriented. The teacher resumes the facilitative role in the concept application phase.

Although the learning cycle model of Barman (1990) and Lawson, Abraham and Renner (1986) exhibits aspects of active learning, it is limited in the sense that it has no evaluation phase. Apart from that, since exploration phase comes first it has the potential to lead the students astray from the focus of the learning. If Introduction phase comes first before exploration the students will be guided as to what should be focused on in the learning during the exploration phase.

Driver-Oldham learning cycle model, on the other hand, is a four-phase teaching sequence developed by Driver and Oldham (1986) and used in Children's Learning-in-Science Project. They made it flexible because of different conceptual areas it is likely to cover in one lesson and also the varying times available for teaching and learning. The first phase is the orientation phase where the students are motivated to learn the concept. At the second phase, elicitation phase, students make their ideas explicit through discussions, creation of posters, or writing. The third phase, restructuring phase, is where the teacher and students clarify and exchange views through discussion, promote conceptual conflict through demonstrations, exchange ideas, and evaluate alternative ideas. At the fourth phase known as application phase, students use their new ideas in familiar and novel settings. They are also given opportunity to review and reflect on how their ideas have changed. The model implicitly incorporates several aspects of technological problem solving and decision-making, notably, evaluation of alternative ideas and reflection at the end of the learning sequence.

These models, whether three-phase or four-phase, are similar in that they centre on a three-stage teaching strategy that involves experience, interpretation, and elaboration. The learning cycle models make students get involved in a sequence of learning activities beginning with exploration of an idea or skill, leading to a more guided explanation, and invention of the idea or skill, and culminating in expansion of the idea or skill through additional practice and trials in new settings. This sequence of learning activities is transformed into a series of lessons on one concept which can last for one or more several instructional periods. Using the learning cycle approach, the teacher introduces the science concept of the lesson in the 2nd stage (rather than defining it at the outset of the lesson as in the traditional approach). The introduced concept subsequently enables students to incorporate their exploration in the 3rd phase and apply it to new examples.

The "5E Learning Cycle" model of (Trowbridge, Bybee & Powell, 2004) has five phases: engagement, exploration, explanation, elaboration and evaluation. At the engagement phase, objects, events or questions are used to engage students in a discussion or brain storming for them to bring out what they know and can do. For the exploration phase, objects and phenomena are explored by students through guided hands-on activities. For explanation phase, students are put in a situation where they explain their understanding of concepts and processes learnt. This phase is characterized by the introduction of new concepts and skills. Conceptual clarity and cohesion are also sought in this phase. The elaboration phase is activity laden and so students apply concepts learnt in contexts, for them to build on their understanding and skill. At the evaluation phase, students assess their knowledge, skills and abilities acquired during the concept learning. A major activity at that phase is the assessment of student learning and lesson effectiveness. The learning cycle models dealt with so far can be effectively used for students at all levels to accomplish conceptual learning.

Cooperative learning is one of the approaches most frequently evidenced in the areas of research and educational applications in addition to being a concept drawing attention among teachers, school administrators and educationalists (Johnson and Johnson, 1999; Slavin & Sharan, 1990; Graham, 2005; Maloof & White, 2005). Cooperative learning, proven to have positive effects on achievement in learning process, is increasingly used in more and more areas everyday (Slavin, Madden, Karweit, Livermon, & Dolan, 1995; Webb, Sydney, & Farivor, 2002; Siegel, 2005). Cooperative learning approach helps students learn many things from each other as well as it encourages them to discuss on a topic and make some evaluations on it (Parker, 1985; Slavin, 1990; Coppola & Lawton, 1995; Gillies, 2006). Cooperative learning can be defined as an approach in which students help each other with an academic issue for a common purpose forming small groups both in and outside the classroom, in which they gain self-confidence, develop their communicative skills, strengthen their problem solving and critical thinking abilities, and participate in teaching-learning process actively (Bolling, 1994; Gardener & Korth, 1996; Bowen, 2000; Levine, 2001; Prince, 2004; Eilks, 2005; Gillies, 2006; Hennessy & Evans, 2006; Lin, 2006; Prichard, Bizo & Stratford 2006). Johnson and Johnson (1999) indicates that a student in a group can individually achieve his/her aims as long as the other members can be successful; and Miller (1989) claims that cooperative learning makes a student depend on others for positive outcomes and rewards. Cooperative learning is a process in which students can achieve a task given to them by working in groups (Slavin, 1995). Other definitions of cooperative learning cover the descriptions of classroom settings in which students perform some academic tasks in small groups in interaction with each other (Parker, 1985). Cooperative learning facilitates this process by enhancing learning through group works. Therefore, students can be more successful, develop their social skills and strengthen their working capacities (Colosi and Zales, 1998). Cooperative learning is regarded to be a mean of preparing students for, when necessary, integrating their energies and working together for a common purpose in various settings at work and home (Mergendoller and Packer, 1989; Bolling, 1994; Eilks, 2005; Gardener & Korth, 1996; Bowen, 2000; Levine, 2001; Prince, 2004; Gillies, 2006; Hennessy & Evans, 2006; Lin, 2006; Prichard et al., 2006). Most cooperative learning techniques use the cooperative learning principles for special purposes.

Much research has been done over the past thirty years on the use of cooperative learning across age groups, ability levels and cultural backgrounds. The results generally suggest that cooperative learning develops higher-order thinking skills (Mathews, Cooper, Davidson, & Hawkes, 1995), enhances motivation, improves interpersonal relations and peer relations (Nastasi & Clements, 1991). Most important, it exploits the diversified abilities of pupils to enhance their cognitive and social performance. Research shows that the performance of low ability students improves in heterogeneous grouping (Webb & Cullian, 1983) because these students receive more elaborated explanations from their high ability peers about the learning materials (Webb, 1992). In the case of high ability students, research shows inconsistent results for their learning outcome. Some research suggests that there is no regression among high ability students (Hooper, Ward, Hannafin, & Clark 1989); others show that they perform as well in heterogeneous as in homogeneous groups (Nastasi & Clements, 1991; Hooper & Hannafin, 1988). Webb (1992) argues that high ability students learn more in heterogeneous than in homogeneous groups because when giving elaborated explanations to the low ability peers, they reorganize and clarify information in different ways, which enhances the development of their meta-cognition.

Individual accountability means that the success of a group depends on the individual learning of all the group members (Johnson & Johnson, 1999; Slavin, Madden, Karweit, Livermon & Dolan, 1995). Apart from responsibility for one's own learning, each member has to be responsible for facilitating the learning of the rest of the group. Individual accountability exists when the performance of each individual member is assessed, the results are given back to the individual and the group to compare against a standard of performance, and the member is held responsible by group mates for contributing his or her fair share to the group's success (Johnson & Johnson, 1999). As such, individual accountability motivates the group members to help one another to exert maximum effort in the learning process (Slavin, Madden, Karweit, Livermon & Dolan, 1995). However, few participants who took part in the study conducted by Slavin et al. (1995) found it difficult for them to accept the concept of individual accountability. Three participants said that they could not convince themselves that they should be held responsible for the learning of their group members. They insisted that learning was a personal thing and a person should get what he had paid for. One of the participants remarked: "It sounds strange to me that one has to be held accountable for others' learning. If a person does not want to learn, he should bear the consequence, but not the members of his group" (p.12). Another participant reiterated: "It's already very good if everyone can be responsible for their own learning. It will be difficult, if not impossible, to go further to ask them to be responsible for each other's learning" (p.12).

Individual accountability can be fostered by the effective use of group reward based on individual performance (Slavin et al. 1995). As members know that for each to get a group reward, the performance of the group, which is determined by the sum of each member's improvement score, must reach an expected level. This extrinsic reward motivates them to learn hard for themselves, as well as to help each other to learn well. With other things being equal, group reward and individual accountability enhance the achievement outcomes of cooperative learning (Slavin et al. 1995).

Jigsaw as a teaching strategy is a cooperative learning strategy that enables each student of a "home" group to specialize in one aspect of a learning unit. Students meet with members from other groups who are assigned the same aspect, and after mastering the material, return to the "home" group and teach the material to their group members. Each piece, which represents student's part, is essential for the completion and full understanding of the final product. If each student's part is essential, then each student is essential. That is what makes the Jigsaw instructional strategy so effective (Bennett, Rolheiser, & Stevahn, 1991). Jigsaw learning allows students to be introduced to material and yet maintain a high level of personal responsibility. In addition, it helps develop a depth of knowledge not possible if the students were to try and learn all of the material on their own. Finally, because students are required to present their findings to the home group, Jigsaw learning will often disclose a student's own understanding of a concept as well as reveal any misunderstandings. The jigsaw teaching strategy has five main steps:

1. Reading with team members,
2. Expert group discussion,
3. Team members report,
4. Test, and
5. Team recognition.

1. Reading with team members:

The class is divided into heterogeneous groups or teams of 4-6 members. Consideration is normally given to the ability levels of the students to ensure that each team has high, middle and low academic achievers. The teacher then distributes to each member a worksheet about the tasks of the day. Each team member is assigned a specific task about the main task. Students are given some few days to read around the task.

2. **Expert group discussion:**

After everyone has read the material, students from different teams with the same task meet in expert groups. A discussion leader who is not necessarily the most able student is assigned to facilitate and to see that everyone participates. Expert group members are given some time to do this. Students may use their textbooks for reference and each student take notes on important and agreed points. Students are motivated to become experts, as they are responsible for teaching that information.

3. **Team reports:**

Students return to their teams. Each expert shares his or her information with the teammates within some minutes per person. The teacher encourages the students to know that they are to be good teachers and good listeners and that the reports should be well organized, concise, and to the point. Students also quiz each other on important points.

4. **Test:**

The whole class then take a test based on the tasks they were given and students are expected to do independent work. The teacher then collects the answered scripts, mark and score. The scores are then used to compute the total score for each team.

5. **Team recognition:**

Using the average score for all the teams as the baseline, the high-scoring team(s) is/are then rewarded.

Teacher Support Materials

Generally, curriculum materials are designed by curriculum developers to support student learning, but the developers often neglect the role teachers play in implementing curriculum materials (Welch, 1979; Stake & Easley, 1978). Thus, the developers of the materials fail to help teachers understand the core vision or how to make productive adaptations that would not misrepresent the vision of the curriculum developers (Krajcik, Mamlok & Hug, 2001). Teachers therefore need support to be able to implement any reform programmes, Researchers have begun to examine the role that curriculum materials play in supporting teachers' learning about reform programmes (Schneider, Krajcik & Blumenfeld, 2005). For example, teaching science in constructivist paradigm as a component in a reform programme entails engaging students in active learning. They need to be able to pose scientific questions, design and conduct investigations to answer those questions, and construct explanations based on evidence (Krajcik, Blumenfeld, Marx & Soloway, 2000). Without support for the teacher how does he accomplish the task. Support materials for teachers have been termed educative curriculum materials (Davis & Krajcik, 2005; Heaton, 2000) or teacher support materials (Mafumiko, 2006). Research has shown that teachers who use teacher support materials can develop their knowledge of content and of learners and expand their repertoire of instructional practices (Schneider & Krajcik, 2002; Schneider, 2006). Despite the potential of teacher support materials, little is known about the extent to which existing science curricula support teacher learning. Project 2061 has conducted reviews of science textbooks using research-based evaluation criteria, but their criteria primarily focused on how well curriculum materials promote students' learning of science, not teachers' learning of how to teach science (Kesidou & Roseman, 2002). Teacher support materials are designed explicitly to promote teachers' learning about teaching as they use the materials to foster students' learning about the subject matter (Davis & Krajcik, 2005). Pedagogical supports within educative materials often appear separately from the student materials, either in teacher-guides or in annotated teacher editions of textbooks. To promote teacher learning, these materials are "designed to speak to teachers, not merely through them" by engaging teachers in "the ideas underlying the writers' decisions and suggestions" (Remillard, 2000, p. 347). Such materials also foster teacher learning by helping teachers make productive and informed decisions about how to respond to students' encounters with the instructional activities (Remillard, 2000). Additionally, teacher support materials that are consistent with any reform of documents can help teachers learn about new ways of teaching science, practice these new ways in their classroom instruction, and reflect upon their experiences (Borko & Putnam, 1996). In these ways, curriculum materials that are designed with explicit pedagogical support can foster the development of teachers' knowledge and practice and thus ultimately contribute to reform efforts.

Students' Conceptual Understanding of Chemical Representations

Students' conceptual understanding of chemical representations is a prominent area of research in chemistry education (Ben-Zvi, Eylon, & Silberstein, 1988; Gabel, 1998). For decades, researchers and chemistry educators have been discussing the three levels of representations in chemistry: macroscopic, microscopic, and symbolic levels (Gabel, 1998; Gabel, Samuel, & Hunn, 1987). Chemical representations at the macroscopic level refer to observable phenomena, such as the change of matter. The microscopic chemistry refers to the nature, arrangement, and motion of molecules used to explain properties of compounds or natural phenomena. Chemistry at the symbolic level refers to the symbolic representations of atoms, molecules, and compounds, such as chemical symbols, formulas, and structures. Empirical studies (e.g. Ben-Zvi, Eylon, & Silberstein 1986, 1987) have shown that learning microscopic and symbolic representations is especially difficult for students because these representations are invisible and abstract while students' understanding of chemistry relies heavily on sensory information. To help students understand chemistry at the three levels, researchers developed new approaches to teaching chemistry such as adapting teaching strategies based on using concrete models and technological tools (Gabel, 1998; Krajcik, 1991). For instance, multimedia tools, which integrate the animation of molecular models, video clips or real time graphics, provide students with opportunities to visualize chemical processes at the microscopic level. According to empirical findings of their studies, Kozma and his colleagues (Kozma, Russell, Jones, Marx, & Davis, 1996) found that the use of multiple linked representations helped students understand chemical equilibrium and its related chemical concepts. Additionally, research supports the advantage of manipulating physical models that help students to visualize atoms and molecules and promote long-term understanding (Barnea & Dori, 1996; Copolo & Hounshell, 1995; Gabel & Sherwood, 1980)

Chemical representations refer to various types of formulas, structures and symbols used to represent chemical processes and conceptual entities (e.g., molecules and atoms). Chemical representations can be viewed as metaphors, models, and theoretical constructs of chemists' interpretation of nature and reality (Hoffman & Laszlo, 1991).The drawing of molecular structures and the writing of chemical formula are "ideology-laden" and "theory-laden" (Hoffmann & Laszlo, 1991) that convey messages of the development of chemical theories and experiments. Chemical representations thus are meaning-based knowledge representations, which are changed and created to reflect the reunification or reconstruction of the theoretical and the experimental. Additionally, representations in chemistry share the following characteristics. First, representations in chemistry are models suitable for specific purposes (Hoffmann & Laszlo, 1991). For example, ball-and-stick models represent the physical positions of atoms and molecules, and space-filling models provide information about the size of atoms that is critical for deciding the conformation of organic molecules. Hence, representations embed selected details of the relevant concepts or principles, but permit other details to fade. Second, the development of representations displays the historical development of theories in this domain. By examining the evolution of the chemists' way of seeing and drawing, Hoffmann and Laszlo stated:

> It [Chemistry] has shed to a large extent its childhood habit of going no further than a phenomenological description of bulk properties, at the macroscopic level. Chemistry has become a microscopic science. Explanations nowadays go routinely, paradigmatically from the microscopic scale to the observable; from the way the electrons are distributed in a dye molecule to its color; from the detailed shape of a molecule and of the electrostatic potential around it to its pharmacological activity. (Hoffmann & Laszlo, 1991, p.8)

That is, microscopic representations currently used in chemistry have evolved from phenomenological analogies of sensory experiences at the macroscopic level. Because these microscopic representations are historically developed and have been extracted from the observable phenomena, understanding these representations becomes a difficult task. For novices, these representations cannot be understood by personal intuition or perceptions. (Hoffmann & Laszlo, 1991) Consistent with this historical development, Gabel, Samuel, and Hunn (1987) indicated that most chemistry concepts have three levels of understanding: the sensory, particulate, and symbolic levels. Chemists transform the sensory information into chemical processes, explain these processes as atomic and molecular behaviors at the particulate level, and translate atoms and molecules into symbols and formulas. This abstract nature of representations is one source of students' learning difficulties. (Hoffmann & Laszlo, 1991). Third, representations in chemistry are symbols, signs or elements of chemical language and vehicles for viewing the world (Hoffmann & Laszlo, 1991; Kozma, Russell, Jones, Marx, & Davis, 1996). Hoffmann and Laszlo (1991) have argued that "a chemical formula is like a word" which composes the language of chemistry and "purports to identify, to single out the chemical species it stands for." The most important implication of this analogy is that both language and chemical representations share the function of communication. In their ethnographic study at a chemistry laboratory, Kozma, Chin, Russell and Marx (1996) found that chemists used representations to communicate with each other and reconstructed reality and nature. They used various representations for asking questions, stating hypotheses, making claims, drawing inferences, and reaching conclusions. Being familiar with these representations and their usage in chemistry, therefore, is essential for the acquisition of expertise. As Kozma indicated (Kozma, 1996), "the use and understanding of a range of representations is not only a significant part of what chemists do in a profound sense it *is* chemistry". Thus, Kozma and Russell (1996) suggested that chemistry education should promote students to develop 'representation competence.' The competence comprises a set of representational skills: the ability to see expressions with different surface features (e.g., changes in color), as representing the same chemical principle or situation, the ability to translate one representation of a chemical concept or situation into another one, and the ability to generate or select an appropriate representations to make explanation, predictions, and justification. Representation knowledge. Recognizing the importance of subject matter knowledge entails understanding the discipline of science and mathematics and being able to articulate and defend a content-specific concept, which are important goals and promote teacher development (Gess-Newsome, 1999). Research on teachers' content knowledge is not new. Shulman and his colleagues initiated a rich line of research, reframing the definition of subject matter knowledge to include the "nature, form, organization, and content of teacher knowledge" (Grossman, Wilson & Shulman, 1989, p.25-26). This broadened definition of subject matter knowledge helped find the links between the knowledge teachers possess, the instructional actions they employ and the learning, attitudes, and beliefs of the students they teach. Shulman (1986) stated, "teachers must not only be capable of defining for students those accepted truths in a domain, but they must also be able to explain why a particular proposition is deemed warranted, why it is worth knowing, and how it relates to other propositions" (p.9). For example, science and mathematics teachers need to know how procedural topics and conceptual topics are interwoven. Teaching involves assisting students to develop their intellectual resources and help them participate in the subject matter that the teachers want them to learn (Morine-Dershimer & Kent, 1999). Research has shown that teachers' subject matter knowledge influences their efforts to help students learn. Teachers' understanding the structure and nature of their discipline and selecting and translating essential content into meaningful learning activities are essential to their subject matter knowledge (Talbert & McLaughlin, 1993). Unfortunately, many high school pre-service teachers will not revisit the topics they will teach until they are in their own classrooms. Much of their understanding of these topics is based on their high school experiences, which were likely to have been taught algorithmically with no conceptual understanding (Goodlad, 1984). The lack of conceptual understanding of the subject matter directly affect teachers' ability to help their students learn in meaningful ways (Ma, 1999; Eisenhart et al, 1993). Ball and McDiramid (1990) stated that in science and mathematics, a critical dimension of knowledge about the subject is the distinction between conventional and logical construction. Critical knowledge about science and mathematics includes relationships within and outside of the field: understanding the relationships among scientific and mathematical ideas and topics and knowing about the relationship between science and mathematics and other fields. Knowing the fundamental activities of the field includes looking for patterns, making conjectures, justifying claims, validating solutions, and seeking generalizations (Ball & McDiramid, 1990). Ma (1999) calls subject matter knowledge understanding "the terrain of fundamental knowledge that is deep, broad, and thorough" or "a profound understanding of a subject" (p. 120). "Although the term profound is often considered to mean intellectual depth, its three connotations, deep, vast, and thorough, are interconnected" (Ma, 1999, p.120). She states that the subject matter knowledge develops when learning and teaching the subject. Subject matter knowledge deepens when teachers prepare for class, teach the material and reflect on the process. "Teachers' subject matter knowledge develops in a cyclic process" (Ma, 1999, p.145). The cycle starts with schooling and provides a base for solid subject matter knowledge. Future teachers learn some scientific competencies in their K-12 education, rather than during their teacher preparation programs. The connections between scientific topics and teaching have begun. It is at this point when subject matter knowledge can be improved. Last, their subject matter knowledge continues to develop during their teaching career only if they are motivated and are provided opportunities to do so, according to Ma (1999). Figure 2 shows the subject matter knowledge cycles through schooling, teaching and teacher preparation.

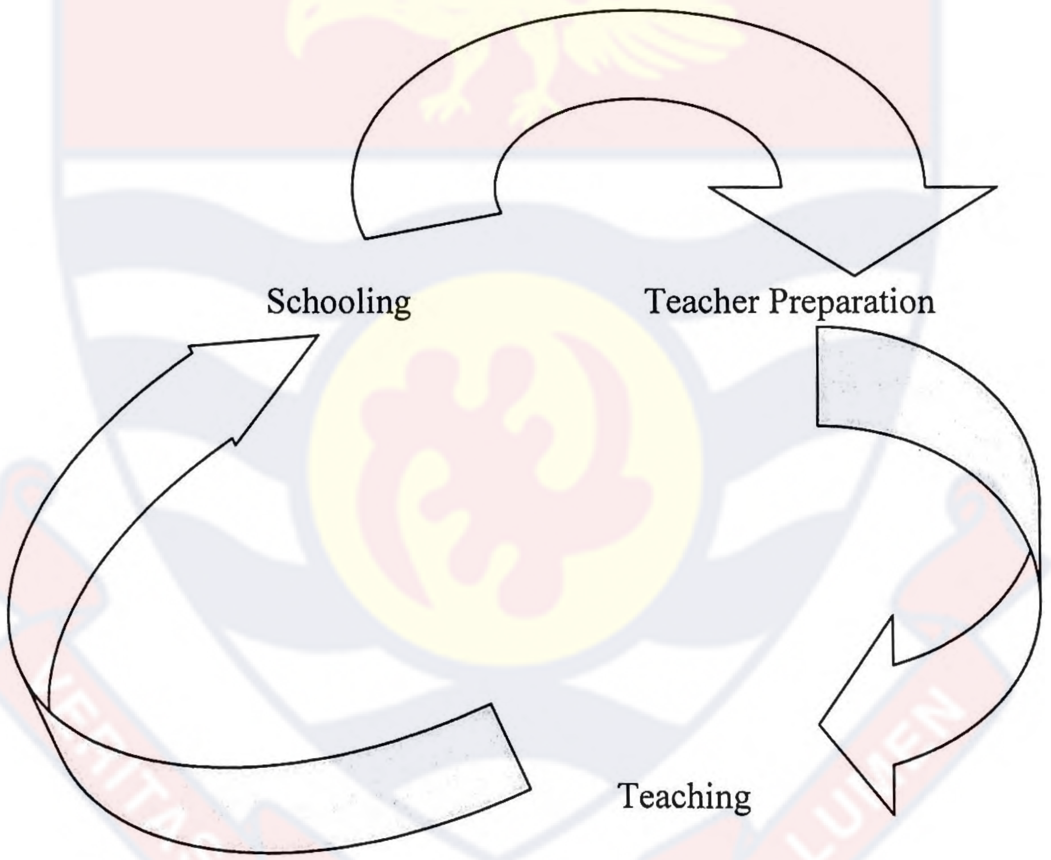


Figure 2: Subject Matter Knowledge Cycle

Subject matter knowledge includes specific information, ideas, and topics that continue to change and grow. This information and these ideas and topics can be subject to disagreement and different interpretations based on competing perspectives within the field (Gess-Newsome, 1999; Ball, 2000; Baturo & Nason, 1996; Even, 1993; Shulman, 1986).

Pedagogical Content Knowledge

Ball (2000) asked what it would take to bring the study of content closer to practice and to prepare teachers to know and be able to use subject matter knowledge effectively in their work as teachers. Rather than view teacher education from the perspective of content or pedagogy, Shulman (1986) believed that teacher education programs should combine these two constituent knowledge domains. Therefore, Shulman (1986) developed a framework for teacher education that included for the first time the concept of pedagogical content knowledge. The use of pedagogical content knowledge as a topic for research and discussion about the nature of an appropriate knowledge base for developing future science teachers steadily increased since its inception (e.g., Shulman, 1986,1987; Wilson, Shulman, & Richert, 1987; Ball, 2000). The discussions of pedagogical content knowledge focused on the knowledge of what is typically difficult for students to learn, the representations that are most useful for teaching a specific subject matter, and ways to develop ideas (Hashweh, 1985; Feiman - Nemser & Buchmann, 1985; Carpenter, Fennema, Peterson & Carey, 1988; Jones, Buckler, Cooper & Stushein, 1997; Ball, 2000; Stohl-Drier, 2001). The sharp distinction between knowledge and pedagogy does not represent a tradition dating back centuries, but rather, a more recent development. A century ago the defining characteristic of pedagogical accomplishment was knowledge of content (Shulman, 1986). Today, we assume that most teachers begin with some expertise in the content they teach. Secondary school teachers typically have completed a major in their content area. Shulman's (1986) central question concerns the transition from pre-service student teacher to novice teacher.

There is a need to know how to blend properly the content aspects of teaching and the elements of the teaching process. If we do not blend content with the teaching process effectively, then the growth of students' scientific reasoning and problem solving skills will be stunted in the classroom (Babttista, 1999; Ball, 2000). Shulman (1986) stated, "conceptual analysis of knowledge for teachers would necessarily be based on a framework for classifying both the domains and categories of teacher knowledge, and the forms for representing that knowledge" (p.10). As the complexities of teacher understanding and transmission of content knowledge is investigated, the need for a more coherent theoretical framework becomes rapidly apparent (Shulman, 1986). How might we think about the growth of knowledge in the minds of teachers, with special emphasis on content? Shulman (1986) suggests three categories of content knowledge: a) subject matter content knowledge, b) pedagogical content knowledge, and c) curricula knowledge. Shulman (1986) defined pedagogical content knowledge as: "[t]he most useful forms of [content] representation . . . the most powerful analogies, illustrations, examples, explanation, and demonstrations in a word, the ways of representing and formulating the subject that makes it comprehensible to others" (p.9). A teachers' pedagogical content knowledge is apparent when analogies between the time it takes to ride a bike a certain distance at a constant speed and linear regression are made. Illustrations of data collected and placed on a graph to make conjectures about the populations from which the samples were taken are a useful form of content representation. Another apparent form of teachers' pedagogical content knowledge is the use of examples of scientific procedures. Knowing how to construct examples means teachers understand both the scientific or mathematical and developmental advantages and disadvantages in the example. The teachers' knowledge of explanations of scientific concepts demonstrates a deep understanding of connections between concepts and procedures, connections across scientific topics, and connections between science and mathematics as well as other disciplines. Analogies, illustrations, examples explanations leads to teachers who can respond appropriately to students' questions, design activities involving an array of scientific representations, and direct scientific discourse in the classroom. Demonstrations, such as the relationship of the quadratic formula with a ball bouncing up and down using a graphing calculator, calculator based laboratory, motion detector and a ball, reveal teachers' knowledge of content representation. Pedagogical content knowledge also includes an understanding of content in a manner that is meaningful to the learner. Teachers should have knowledge of the conceptions their students bring with them to science classrooms. "If those conceptions are misconceptions, which they often are, teachers need knowledge of the strategies most likely to be fruitful in reorganizing the understanding of learners" (Shulman, 1986, p.9). In 1987, pedagogical content knowledge was listed by Shulman as one of the seven knowledge bases for teaching, removing it as a subcategory and placing it on equal footing with content knowledge, general pedagogical knowledge, curricula knowledge, learners knowledge, educational contexts knowledge, and philosophical and historical aims of education knowledge. Pedagogical content knowledge was then defined as:

> That special amalgam of content and pedagogy that is uniquely the providence of teachers, their own special form of professional understanding . . . Pedagogical content knowledge . . .identifies the distinctive bodies of knowledge for teaching. It represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to diverse interests and abilities of learners, and presented for instruction. Pedagogical content knowledge is the category most likely to distinguish the understanding of the content specialist from that of the pedagogue. (Shulman, 1987, p.8)

Grossman (1990) defined "four general areas of teacher knowledge . . .as the cornerstones of the emerging work on professional knowledge for teaching: general pedagogical knowledge, subject matter knowledge, pedagogical content knowledge, and knowledge of context" (p.5). Of the four knowledge bases, pedagogical content knowledge was anticipated as having the greatest impact on teachers' classroom actions. Research in the Third Handbook of Research on Teaching (1990) has exponentially increased within the area of teachers' understandings of subject matter knowledge. Pedagogical content knowledge is now a commonly accepted construct in the educational community. Books and chapters have been dedicated to the exploration of teachers' knowledge of subject matter in general (Ball & McDiramid, 1990; Brophy, 1991). It has been used as a major organizing construct in reviews of the literature on teachers' knowledge (Borko & Putnam, 1995). Pedagogical content knowledge has the characteristics of a good model. The study of teacher knowledge in various subject areas such as science, mathematics, social studies and english language research has been revitalized. In addition, pedagogical content knowledge provides a new analytical frame for organizing and collecting data on teachers' cognition. The model has also highlighted the importance of subject matter knowledge and pedagogical knowledge.

Chemical Formulae and Chemical Equations in the Junior and Senior High Schools Science Curricula

The objectives of the teaching science syllabus 2010, relating to chemical formulae and chemical equations for Junior High School Science Curriculum are that at the end of the lesson, students should be able to :

1. define a chemical compound
2. name some examples of compounds
3. write the chemical formulae of some compounds such as FeS, NaCl, CuO etc
4. write the systematic names of simple compounds such as Iron (II) sulphide (FeS), Copper (II) oxide etc.
5. write word equations for some simple reactions such as Iron + sulphur = Iron (II) sulphide, Sodium + chlorine = Sodium chloride etc
6. balance simple chemical equations such as

$N_2 + H_2 \longrightarrow NH_3$

In the recommended science textbook for Junior High Schools, the concept of chemical formulae and chemical equations is entitled chemical substances. Under this topic, the first 20 elements and their symbols are presented and this is followed by the periodic table of the first 20 elements. Then presentation on formation of cations and anions conclude chemical substances unit 1. Chemical substances unit 2 begins with an activity that is in the form of review of atoms, elements, symbols of first 20 elements and ions and how they are formed. The next is a second activity on observing a reaction. This is followed by a table and in the table; there are three elements (metals) in one column and three other elements (non-metals) in another column. In the third column, there are names of the formulae that those elements in the first and second columns would form and the formulae of the compounds they form are in the in the last column and examples are as shown in table 1.

Table 1-*Names and Formulae of some Binary Compounds Formed from a Metal and Non-Metal*

Metals	Non-metals	Name of compound	Formula of compound
Na	Cl	Sodium chloride	NaCl
Fe	S	Iron (II) sulphide	FeS

In the table above, the formula of the compound should have come before the name of the compound. Also something should have been done about how the formulae were arrived at so that students would know how these formulae came about as this can also prevent rote learning. On the naming of the compound formed, the book gave the steps as

1. In binary compounds the name of the metal element is always written first
2. The name of the non-metal element which comes second is changed to end in –ide
3. Some metals have a (II) after their name in the compound. The (II) shows that they lose two electrons when they form a compound.

Concerning chemical equations, the textbook touched on word and symbol equations. magnesium + oxygen $\longrightarrow$ magnesium oxide was used as an example. On how to balance chemical equation, the textbook gave the following four steps

1. Write out the word equation
2. Write down the correct formulae for the reactants and products
3. Count the number of atoms of each element on each side of the equation
4. Balance the numbers of each kind of atom on each side using multiples of molecules

This concluded the concept of chemical formulae and chemical equations under the topic chemical substances 2 in the Junior High School science curriculum.

The WAEC syllabus for Senior High School Chemistry under the topic Stoichiometry and Chemical Reactions talks briefly on symbols, chemical formulae and chemical equations. Under this, students are to be taught calculations involving chemical formulae and chemical equations.

In the recommended chemistry textbook for Senior High Schools, chapter 5 of the book is entitled chemical formulae and chemical equations. The objectives of the chapter relating to chemical formulae and chemical equations are that students should be able to:

1. write the chemical formulae for common inorganic compounds
2. use oxidation numbers to name common inorganic compounds given their formula
3. write chemical equations from given information
4. balance simple equations

The textbook then started with atoms and said symbols of elements are used to denote them with examples as Na, H, O etc. This is followed by the sub-topic molecules under which explanation on atomicity is given with examples. This is followed by ionic compounds under which ions of some elements are presented. Polyatomic ions or radicals are also explained with examples under ionic compounds. The next sub-topic is names of formulae and under this it explained the naming of chemical substances as chemical nomenclature. It stated that the naming of inorganic compounds relies on oxidation numbers therefore it went ahead to explain what oxidation numbers are with examples. Under naming of compounds, it first explained what binary compounds are and gave the steps in naming them as

1. the suffix –ide replaces the last two or three letters in the name of the more electronegative
2. the oxidation number of the more electropositive atom is placed in bracket in capital Roman numerals after the name of the element.

Then a table showing some elements, the formulae of their ions and the name of the ions is drawn. After this, another table is drawn showing some formulae of compounds in one column and the names of the compounds in another column as few examples are shown below in Table 2.

Table 2-*Names of some Binary Compounds*

Formula	Name of binary compound
Mg_3N_2	Magnesium nitride
Cu_2O	Copper (I) oxide
FeS	Iron (II) sulphide

The sub-topic Ions followed and under this a table of some common cations and their names is drawn. About oxoanions the textbook stated that the naming of oxoanions is based on the oxidation number of the central atom that it is bonded to and gave the following steps for naming them

1. the suffix-ate replaces the last two or three letters in the name of the central atom
2. the oxidation number of the central atom is placed in brackets in capital Roman numerals after its name.

3. the number of oxygen atoms is placed before the name of the central atom as dioxo, trioxo, tetraoxo, pentaoxo, hexaoxo etc for 2, 3, 4, 5 and 6 oxygen atoms. One oxygen atom is not given a prefix.
4. the word ion is added to the name.

On oxoacids, the above steps apply except the step 4 where the word acid replaces the word ion in the name of the oxoanion. A table of oxoanions and their names is then drawn as few examples are shown below in Table 3.

Table 3-*Oxoanions and their Names*

Oxoanion	Name of ion
SO_4^{2-}	tetraoxosulphate (VI) ion
MnO_4^-	tetraoxomanganate (VII) ion
CO_3^{2-}	trioxocarbonate (IV) ion

This is followed by another table on some common inorganic acids and their names as few of them are shown in Table 4

Table 4-*Inorganic Acids and their Names*

Acid	Name of acid
H_2SO_4	tetraoxosulphate (VI) acid
HNO_3	trioxonitrate (V) acid
H_3PO_4	tetraoxophosphate (V) acid

About bases and salts, the bases were divided into two groups, namely oxides and hydroxides. The salts were also divided into two groups, namely the binary salts and the oxoacid salts.

Oxides and binary salts are named as binary compounds. Hydroxides are named in a similar way to binary compounds. The name of the cation is written first, followed by the oxidation number if it varies. The word hydroxide is then added example Copper (II) hydroxide for $Cu(OH)_2$. Oxoacid salts are named by writing the cation first followed by its oxidation number, if it varies. The name of the oxoanion is then added; for example Zinc trioxocarbonate (IV) for $ZnCO_3$. The names of other salts not mentioned so far are combination of the names of cations and anions for example Sodium chloride for NaCl. Some salts and other compounds have water molecules as part of their structures. The name of the substance without water (anhydrous) is followed by the number of water molecules example penta-, tetra-, hexa- etc. The number of water molecules can also be represented as a pure number separated by a dash plus the word water. Example $CuSO_4. 5H_2O$ is named as Copper (II) tetraoxosulphate (VI) pentahydrate or Copper (II) tetraoxosulphate (VI)-5-water. The textbook closed the lesson on chemical formulae by giving the students five steps to guide them in writing the correct formula for a given name of a compound.

On chemical equations, the textbook explained what it is, gave its components and indicated that chemical reactions are represented by chemical equations. It said that to write balanced chemical equations, the names or symbols and formulae of substances in the reaction must be correct. The book explained what a balanced chemical equation is and went ahead to give four steps to guide students in balancing chemical equations.

Chief Examiners' Reports on Performance of students in Chemical Formulae and Chemical Equations in Chemistry Examinations at the Senior High School Level

Chief Examiners' (CE) reports available at the West African Examinations Council (WAEC) reveal that senior high school students have difficulty in writing chemical formulae and chemical equations. In 1994, the CE report indicated that most candidates could not write balanced chemical equation in the chemistry paper at the Senior Secondary School Certificate Examination (SSSCE). In the chemistry practical examination of the same year, the CE stated that Sodium trioxcarbonate (IV) and Sodium hydrogen trioxcarbonate (IV) were badly written as NACO and NA_2HCO_3 respectively. In 1995, the CE report stated that many candidates had problems with writing chemical equations and the systematic naming of inorganic compounds. In 1999, the CE report indicated that students were unable to write equations for reactions between Bronsted Lowry bases and concentrated HCl. The report also stated that students were unable to give the IUPAC names of some given compounds. In 2001, the CE report said that writing of chemical formulae and writing of ionic equations was poorly handled by candidates. A summary of candidates' weaknesses of the 2003 CE report said that candidates could not balance chemical equations.

The 2004 chemistry theory paper required candidates to write a balanced chemical equation for the production of oxygen when $KClO_3$ is heated and then calculate the volume of dry oxygen gas evolved. The examiners' CE report on the above question was that candidates had problems writing the equation correctly and hence could not get the correct mole ratio. In 2005, a summary of candidates' weaknesses of the CE report indicated that candidates had problems writing chemical equations and formulae of substances. In the summary of candidates' weaknesses of chemistry 2 (theory) paper of the 2008 WASSCE, the chemistry chief examiner lamented that most of the candidates had problems writing chemical equations. The report went further to state that in question 5(c) of the same paper, students were requested to write balanced chemical equation for the thermal decomposition of each of the following compounds:

(i) Li_2CO_3

(ii) K_2CO_3

(iii) $LiNO_3$

The chief examiner's comment was that the above question posed problems to most candidates. Also in the 2009 examiner's report, question 4(d) of the chemistry 2 (theory), paper requested the students to write a balanced chemical equation for the reaction between sodium and water and then use the equation to determine the volume of the gas produced at STP. The chemistry chief examiner's report on this question was that most candidates could not write the correct equation between sodium and water. Lastly, in 2013, the Q3(a)(ii) of the chemistry 2 paper requested students to write chemical equations to show that aluminium oxide is amphoteric. According to the Chief Examiner, majority of the candidates could not write the equation of Al_2O_3 with a base.

A Study on SHS Students' Difficulties and Understanding of Writing Chemical Formulae and Chemical Equations

In a study conducted by Baah (2009) to investigate Senior High School students understanding of chemical formulae and chemical equations, 334 senior high school science students drawn from all the schools offering science in the New Juaben Municipality of the Eastern Region were used. The study was put into four sections:

1. Senior High School Students' Difficulties and Understanding of Writing Chemical Formulae of Inorganic Compounds
2. Senior High School Students' Ability to Determine Number of atoms of each Element in Binary and Ternary Compounds
3. Senior High School Students' Ability to Determine Ions and their Subscripts in Compounds
4. Senior High School Students' Difficulties and Understanding of Writing Chemical Equations

Senior High School Students' Difficulties and Understanding of Writing Chemical Formulae of Inorganic Compounds

In the first section, students were given the IUPAC names of six inorganic compounds to write their chemical formulae. The compounds were:

a. Copper (I) oxide

b. Iron (II) sulphide

c. Copper (II) tetraoxophosphate (V)

d. Calcium trioxonitrate (V)

e. Ammonium trioxocarbonate (IV)

f. Silver nitride

The performances of the students are discussed below:

Qa **Copper (I) oxide**

Out of 334 students who participated in the study, 40.4% could write the correct chemical formula of Copper (I) oxide as Cu_2O. From the results of their performance, 59.6% out of the 334 students who took part in the study could not write the correct chemical formula of Copper (I) oxide. Students' responses and reasons for their inability are presented in Table 5.

Qb. **Iron (II) sulphide**

From the results a total of 53.3% of students out of 334 students involved in the study could not write the correct chemical formula of Iron (II) sulphide. Their responses and reasons for this failure are presented in Table 6.

Qc **Copper (II) tetraoxophosphate (V)**

Only 11.1% of 334 students who participated in the study was able to write the correct chemical formula of Copper (II) tetraoxophosphate (V) as $Cu_3(PO_4)_2$. That means 88.9% could not write the correct chemical formula of Copper (II) tetraoxophosphate (V). This is indeed a huge failure and reasons given by these students for their wrong answers are presented in Table 7.

Qd. **Calcium trioxonitrate (V)**

An overall 67.4% of students who took part in the study could not write the correct chemical formula of Calcium trioxonitrate (V). Responses of students who got the chemical formula wrong and typical reasons assigned for writing the compound the way they did are presented in Table 8.

Qe. **Ammonium trioxocarbonate (IV)**

Out of 334 students involved in the study, only 31.7% was able to write the correct chemical formula of Ammonium trioxocarbonate (IV) as $(NH_4)_2CO_3$. Therefore a total of 68.3% of students who participated in the study could not write the correct chemical formula of Ammonium trioxocarbonate (IV). Their reasons and responses that explain their inability are presented in Table 9

Qf **Silver nitride**

Out of 334 students who took part in the study, only 8.1% was able to write the correct chemical formula of Silver nitride as Ag_3N. Hence an overall 91.9% of the students who participated in the study could not write the correct chemical formula of Silver nitride. This is very serious. The answers and reasons given by these students for this failure are presented in Table 10.

Table 5-*Students' Responses and Reasons for Writing the Chemical Formula of Copper (I) oxide Wrongly (N = 199)*

Chemical formula given by students	Students' reasons for the formula provided	Number and Percentage of students
CuO	Copper (I) is Cu and oxide is O	120 (60.3%)
CuO^-	Copper (I) is Cu^+ Oxide is O^{2-}	50 (25.1%)
CuO_2^-	Copper (I) is Cu Oxide is O^{2-}	29 (14.6%)

Table 6-*Students' Responses and Reasons for Writing the Chemical Formula of Iron (II) sulphide Wrongly (N = 178)*

Chemical formula given by students	Students' reasons for the formula provided	Number and Percentage of students
Fe_2S	Iron (II) is Fe_2 and Sulphide is S	107 (60.1%)
$Fe(SO_3)_2$	Iron is Fe and sulphide is SO_3 but it is multiplied 2 because it is bonded to Iron (II)	38 (21.3%)
$Fe(SO)_2$	Iron is Fe and sulphide is SO but it is multiplied by 2 because it is bonded to Iron (II)	10 (5.6%)
FeS_2	Iron is Fe and sulphide is S but it is multiplied by 2 because it is bonded to Iron	23 (13.0%)

Table 7-*Students' Responses and Reasons for Writing the Chemical Formula of Copper (II) tetraoxophosphate (V) Wrongly (N = 297)*

Chemical formula given by students	Students' reasons for the formula provided	Number and Percentage of students
$CuPO_4$	Copper (II) is Cu^{2+} and tetraoxophosphate (V) ion is PO_4^{2-}	165 (55.6%)
$Cu(PO_4)_2$	Copper (II) is Cu^{2+} tetraoxophosphate (V) ion is PO_4^-	70 (23.6%)
Cu_2PO_4	Copper (II) is Cu_2 and tetraoxophosphate (V) is PO_4	42 (14.1%)
Cu_2P_4	Copper (II) is Cu_2 tetraoxophosphate (V) is P_4	20 (6.7%)

Table 8-*Students' Responses and Reasons for Writing the Chemical Formula for Calcium trioxonitrate (V) Wrongly (N = 225)*

Chemical formula given by students	Students' reasons for the formula provided	Number and % of students
$CaNO_3$	Calcium ion is Ca^+ and nitrate ion is NO_3^-	141 (62.7%)
$Ca(NO)_2$	Calcium ion is Ca^{2+} and nitrate ion is NO^-	30 (13.3%)
Ca_3N	Calcium ion is Ca^+ and nitrate ion is N^{3-}	30 (13.3%)
Ca_3N_2	Calcium ion is Ca^{2+} and nitrate ion N^{3-}	24 (10.7%)

Table 9-*Students' Responses and Reasons for Writing the Chemical Formula of Ammonium trioxocarbonate (IV) Wrongly (N = 228)*

Chemical formula given by students	Students' reasons for the formula provided	Number and Percentage of students
NH_4CO_3	ammoniun ion is NH_4^+ and Carbonate ion is CO_3^-	114 (50.0%)
$NH_4(CO)_3$	ammoniun ion is NH_4^+ and Carbonate ion is CO_3^-	51 (22.4%)
NH_4C	ammoniun ion is NH_4^+ and Carbonate ion is C^-	39 (17.1%)
NH_4CO	ammoniun ion is NH_4^+ and Carbonate ion is CO^-	24 (10.5%)

Table 10-*Students' Responses and Reasons for Writing the Chemical Formula of Silver nitride (IV) Wrongly (N = 307)*

Chemical formula given by students	Students' reasons for the formula provided	Number and Percentage of students
$AgNO_3$	Silver ion is Ag^+ and nitride ion is NO_3^-	92 (30.0%)
AgN_3	Silver ion is Ag^+ and nitride ion is N^{3-}	89 (29.0%)
$AgNO_2$	Silver ion is Ag^+ and nitride ion is NO_2^-	50 (16.2%)
SiN	Silver ion is Si^+ and nitride ion is N^-	76 (24.8%)

Summary of Students' Difficulties in Writing Chemical Formulae

From Tables 5-10 the problems SHS students have in writing chemical formulae of inorganic compounds became clear. They are:

1. students do not understand the meaning of Roman numerals that are put in brackets of IUPAC names of compounds.
2. students have problem with what valencies are and do not understand the role they play in writing of chemical formulae.
3. Students cannot write the correct names and formulae of some radicals
4. tetraoxophosphate (V) ion and the nitride ion are not familiar to the students.
5. Combination of some cations and anions to form neutral compounds is a problem to the students.

Students' Ability to Determine Number atoms of each Element in Binary and Ternary Compounds

In the section two of the study conducted by Baah (2009), the science students were given three compounds to determine the number of atoms of the various elements present. The compounds were:

a. Potassium trioxochlorate (V)

b. Copper (II) tetraoxophosphate (V) and

c. Aluminium oxide

Generally, determining the number of atoms of each element from the IUPAC name of compounds was a problem to the students. Determination of the number of atoms of each element in Copper (II) tetraoxophosphate (V) posed much difficulty to the students. This is because out of 334 science students who participated in the study, 304 students could not determine correctly the number of atoms of each element of the compound. From the results of their performance, 165 (54.3%) of the students wrote the formula of the compound as $CuPO_4$ hence their inability. Also 70 (23.0%) of the students wrote the formula as $Cu(PO_4)_2$. Again 42 students wrote the formula as Cu_2PO_4. Out of the number who took part in the study, 6.6% wrote the formula as Cu_2P_4 and 2.3% wrote the formula as $Cu_3(PO_4)_2$. Hence the wrong formulae they wrote gave way to their failure. Also a total of 56.0% of the students could not determine correctly the number of atoms of each element in the compound Potassium trioxochlorate (V) largely because of wrong formula they wrote which contributed to their wrong answers. For the compound

Aluminium oxide, 51.4% of the students wrote the formula as AlO and 31.8% also wrote the formula as Al_2O hence could not determine the number of atoms correctly.

From the above study conducted, it can be seen that students' inability to write correct chemical formulae hampers them from determining the correct number of atoms of each element in a compound.

Students' Ability to Determine Ions and their Subscripts in Compounds

In this section, the students were given the same compounds as in section two as:

a. Potassium trioxochlorate (V)

b. Copper (II) tetraoxophosphate (V)

c. Aluminium oxide

Out of 334 students involved in the study, only 11.1.0% was able to determine correctly the ions in Potassium trioxochlorate (V) as K^+ and ClO_3^- and their subscripts as K^+ : 1 and ClO_3^- : 1. Responses and reasons given by these students are shown in Table 11. Only 2.1% and 11.7% out of 334 students involved in the study was able to determine correctly the ions and their subscripts in Copper (II) tetraoxophosphate (V) and Aluminium oxide respectively. Reasons assigned for this failure are shown in Tables 12 and 13 respectively.

Table 11-*Students Responses and Reasons for Identifying Subscripts of Ions in Potassium trioxochlorate (V) Wrongly (N = 297)*

Number and Percentage of students	Reasons for students' inability
101 (34.0%)	Wrong subscripts determined from wrong formulae KCl_3 and K_3Cl_5 and from wrong ions - K^+ and Cl^-
90 (30.3%)	Wrong subscripts determined from wrong formula K_2ClO_3 and from wrong ions K^+, Cl^- and O^{2-}
89 (30.0%)	No response because the compound is neutral and therefore has no ions
17 (5.7%)	No response because of lack of knowledge about subscripts.

Table 12-*Students Responses and Reasons for Identifying Subscripts of Ions in Copper (II) tetraoxophosphate (V) Wrongly (N = 327)*

Number and Percentage of students	Reasons for students' inability
167 (51.1%)	Wrong subscripts determined from wrong formula $CuPO_4$ and from wrong ions Cu^{2+} and PO_4^{2-}
70 (21.4%)	Wrong subscripts determined from wrong formula $Cu(PO_4)_2$ and from wrong ions Cu^{2+} and PO_4^-
90 (27.5%)	No response because the compound is neutral and therefore has no ions

Table 13-*Students Responses and Reasons for Identifying Subscripts of Ions in Copper (II) tetraoxophosphate (V) Wrongly (N = 327)*

Number and Percentage of students	Reasons for students' inability
167 (51.1%)	Wrong subscripts determined from wrong formula $CuPO_4$ and from wrong ions Cu^{2+} and PO_4^{2-}
70 (21.4%)	Wrong subscripts determined from wrong formula $Cu(PO_4)_2$ and from wrong ions Cu^{2+} and PO_4^{-}
90 (27.5%)	No response because the compound is neutral and therefore has no ions

From the responses given by students, it became evident once again that students inability to write correct chemical formulae makes it difficult for them to determine the correct formulae of ions which bond to form ionic compounds.

Senior High School Students' Difficulties and Understanding of Writing Chemical Equations

The last section of the study conducted by Baah (2009) investigated the difficulties and understanding senior high school students have on writing of chemical equations. The section was further divided into two parts. In the first part, students were given five incomplete equations of reactions with only the reactants given and they were expected to predict the product(s) and balance the entire equations.

The incomplete equations given to them were:

a. $CO_2 + CaO \longrightarrow$

b. $C_4H_{10} + O_2 \longrightarrow$

c. $Ca(OH)_2 + H_3PO_4 \longrightarrow$

d. $CaCO_3$ + heat $\longrightarrow$

e $AgNO_3 + NaCl \longrightarrow$

The proportion of students who predicted the products correctly in the various schools are shown in Table 15. Generally, the performance of the schools in the test above was not good especially in questions (b) and (c). This is because not even half of the students from any of the schools predicted the products of reactions (b) and (c) correctly. Students' responses and reasons for this poor performance in predicting the products of reactions (b) and (c) are presented in Tables 14 and 16 respectively.

The main difficulty on the part of the students who could not predict the products of reaction (b) was their lack of knowledge of the fact that when a hydrocarbon is burnt in oxygen, it yields carbon (IV) oxide and water as products. For reaction (c), the main difficulty was inability to write the correct formula of calcium tetraoxophosphate (V).

Table 14-*Students Reasons for Predicting the Products of Reaction (b) Wrongly (N = 292)*

Products provided by students	Reasons for providing such products	Number and Percentage of students
$C_4H_{10}O_2$	Because C_4H_{10} reacted with O_2	72 (24.7%)
$C_2H_5 + O_2$	Because C_4H_{10} on burning, will split into 2 moles of C_2H_5 with O_2 released.	82 (28.1%)
$C_4 + H_2O$	Because carbon and water will be the products	48 (16.4%)
$CO_2 + H_2$	Because carbon (IV) oxide and hydrogen gas will be the products	56 (19.2%)
No response	Because of lack of knowledge about combustion reactions involving hydrocarbons.	34 (11.6%)

Table 15-*Schools Performance on Prediction of Products of Reactions*

Schools	N	Qa	Qb	Qc	Qd	Qe
A	70	43 (61.4%)	8 (11.4%)	5 (7.1%)	36 (51.4%)	34 (48.6%
B	30	27 (90.0%)	2 (6.7%)	2 (6.7%)	19 (63.3%)	17 (56.7%
C	80	63 (78.8%)	27 (33.8%)	30 (37.5%)	50 (62.5%)	60 (75.0%
D	55	52 (94.5%)	3 (5.5%)	15 (27.3%)	45 (81.8%)	46 (83.6%
E	42	15 (35.7%)	0 (0.0%)	1 (2.3%)	13 (31.0%)	9 (21.4%
F	35	30 (85.7%)	1 (2.9%)	3 (8.6%)	21 (60.0%)	20 (57.1%
G	22	17 (77.3%)	1 (4.5%)	1 (4.5%)	13 (59.1%)	13 (59.1%
Overall	334	247 (74%)	42 (12.6%)	57 (17.1%)	197 (59.0%)	199 (59.6%

Table 16-*Students Reasons for Predicting the Products of Reaction (c) Wrongly (N = 277)*

Products provided by students	Reasons for providing such products	Number and Percentage of students
$CaPO_4 + H_2O$	Because salt $CaPO_4$ and water H_2O will be the products	92 (33.2%)
$CaPO_4 + H_2O + H_2$	Because salt $CaPO_4$, water H_2O and hydrogen gas will be the products	73 (26.4%)
$(CaPO_4)_2 + H_2O$	Because salt $(CaPO_4)_2$ and water H_2O will be the products	70 (25.3%)
No response	Because writing the formula of the salt Calcium tetraoxophosphate (V) was a problem.	42(15.1%)

The main difficulty on the part of the students who could not predict the products of the reactions was their inability to write the correct formulae of the products they predicted. Also for reaction (b) the main difficulty the students encountered was their lack of knowledge of the fact that when a hydrocarbon is burnt in oxygen, it yields carbon (IV) oxide and water as products.

In the second part of section four, students were given four reactions in statement form and they were expected to write each reaction in symbols and then balance the entire equation. The statement reactions were:

a. Barium chloride reacts with potassium tetraoxosulphate (VI) to form barium tetraoxosulphate (VI) and potassium chloride

b. Potassium hydroxide reacts with tetraoxophosphate (V) acid to form potassium tetraoxophosphate (V) and water

c. Decomposition of potassium trioxochlorate (V) on application of heat to form potassium chloride and oxygen

d. Combustion of propane to form carbon (IV) oxide and water

As shown in Table 17, the general performance of the students in the test on translation of statement reactions to chemical equations in symbols was poor. Considering statement reaction (a), only school D out of the 7 schools had more than half of its students who did correct translation of the reaction into equation. In school A, less than one-fifth of the students did correct translation of reaction (a). In school C, less than half of the students answered item (a) correctly. In school E, less than one-tenth of the students could translate correctly statement reaction (a) into equation in symbols. In schools B, F and G less than one-third, less than one-fourth and less than half of the students respectively could translate statement reaction (a) into equation in symbols. Performance in statement reaction (b) was poor because not even half of the students from any of the schools could correctly translate the reaction into equation. In school E, none of the students was able to translate the reaction (b) correctly and in schools B and F, less than 10% of the students who participated in the study translated the statement reaction (b) correctly into equation. For statement reaction (c), it was only in schools C and D that more than half of their students translated reaction (c) correctly. In school A, less than one-fourth of the students could translate the statement reaction (c) correctly. In school E only one student translated statement reaction (c) correctly and in school G less than one-fourth could perform the same task for reaction (c) correctly. Considering statement reaction (d), less than one-third of the students in school A translated that reaction correctly into equation in symbols. In schools B, F and G not even half of the students in those schools could translate reaction (d) into equation in symbols and in school E, none of the students was able to perform the same task for reaction (d).

For reaction (a) the main difficulties identified were: students' inability to write the correct symbol of Barium and inability to write the correct chemical formulae of the compounds: Barium chloride, Potassium tetraoxosulphate (VI) and Barium tetraoxosulphate (VI). The main difficulty identified for reaction (b) was students' lack of knowledge about the correct formula of tetraoxophosphate (V) acid which also made it difficult for them to write the correct chemical formula of Potassium tetraoxophosphate (V). The difficulties in reactions (c) and (d) were: inability to write the correct formula of Potassium trioxochlorate (V) and inability to write the correct formula of Propane respectively.

Table 17-*Schools Performance on Translation of Statement Reactions into Chemical Equations in Symbols*

Schools	N	Qa	Qb	Qc	Qd
A	70	11 (15.7%)	8 (11.4%)	17 (24.3%)	19 (27.1%)
B	30	8 (26.7%)	2 (6.7%)	10 (33.3%)	12 (40.0%)
C	80	33 (41.3%)	24 (30.0%)	45 (56.3%)	48 (60.0%)
D	55	30 (54.5%)	20 (36 .4 %)	30 (54.5%)	40 (72.7%)
E	42	4 (9.5%)	0 (0.0%)	1 (2.4%)	0 (0.0%)
F	35	7 (20.0%)	3 (8.6%)	13 (37.1%)	17 (48.6%)
G	22	9 (40.9%)	4 (18.2%)	5 (22.7%)	5 (22.7%)
Overall	334	28 (21.7%)	9 (7.0%)	29 (22.5%)	34 (26.4%)

Conceptual Framework

Successful students are actively involved in their own learning; they monitor their thinking, think about their learning and assume responsibility for their own learning. Research has shown that learning activity that deliberately uses the social and physical context are producing more understanding of learning or cognition and that for concepts to be learnt effectively the learners must interact with their environment. Also, teachers who use teacher support materials can develop their knowledge of content and of learners and expand their repertoire of instructional practices. In this study, learners were actively involved in knowledge creation and determination of solution to problems and were responsible for whatever solution they had at the end of the day.

Shulman (1986) defined pedagogical content knowledge as: "the most useful forms of [content] representation, the most powerful analogies, illustrations, examples, explanation, and demonstrations in a word, the ways of representing and formulating the subject that makes it comprehensible to others" (p.9). The researcher through his experience as a chemistry teacher designed the PCK material in the form of a game which basically employs illustration, explanation and demonstration.

PCK can be understood as the knowledge that can be used by teachers to transform their subject matter knowledge into teachable content knowledge (Geddis, Onslow, Beynon, & Oesch, 1993). Several international studies on PCK have been conducted (Adams & Krockover, 1997; Carlsen, 1993; Grossman, 1990; Magnusson, Krajcik, & Borko, 1999; Marks, 1990) which have identified the components of PCK. These components include: 1) knowledge and beliefs of teaching objectives, 2) knowledge and beliefs of the science curriculum, 3) knowledge and beliefs of teaching strategies, 4) knowledge and beliefs of students' understanding of science, and 5) knowledge and beliefs of learning assessment. The teaching and learning material developed in this study is based on the science curriculum for JHS and SHS and their teaching objectives. The teaching and the assessment strategies that the material employs are all clearly outlined in the teaching syllabi of both JHS and SHS.

For decades, researchers and chemistry educators have been discussing the three levels of representations in chemistry: macroscopic, microscopic, and symbolic levels. Chemical representations at the macroscopic level refer to observable phenomena, such as the change of matter. The microscopic chemistry refers to the nature, arrangement, and motion of molecules used to explain properties of compounds or natural phenomena. Chemistry at the symbolic level refers to the symbolic representations of atoms, molecules, and compounds, such as chemical symbols, formulas, and structures. Literature has revealed that learning microscopic and symbolic representations is especially difficult for students because these representations are invisible and abstract. To help students understand chemistry at the three levels, researchers developed new approaches to teaching chemistry such as adapting teaching strategies based on using concrete models and technological tools. Hence literature supports manipulation of physical models by students in learning because it will help them to visualize atoms and molecules and promote long-term understanding.

Summary of Literature Reviewed and Implications for the Study

The literature that has been reviewed has shown that successful students are actively involved in their own learning; they monitor their thinking, think about their learning and assume responsibility for their own learning and that the advantage learner-centered teaching has over teacher-centered teaching is that schools attain higher rates of student retention and have better prepared graduates than those students who were more traditionally trained. The review of literature has also shown that learning activity that deliberately uses the social and physical context are producing more understanding of learning or cognition and that for concepts to be learnt effectively the learners must interact with their environment. The review of literature has shown that teachers who use teacher support materials can develop their knowledge of content and of learners and expand their repertoire of instructional practices.

The review hinted that for decades, researchers and chemistry educators have been discussing the three levels of representations in chemistry: macroscopic, microscopic, and symbolic levels. Chemical representations at the macroscopic level refer to observable phenomena, such as the change of matter. The microscopic chemistry refers to the nature, arrangement, and motion of molecules used to explain properties of compounds or natural phenomena. Chemistry at the symbolic level refers to the symbolic representations of atoms, molecules, and compounds, such as chemical symbols, formulas, and structures. It was found in the literature that learning microscopic and symbolic representations is especially difficult for students because these representations are invisible and abstract. To help students understand chemistry at the three levels, researchers developed new approaches to teaching chemistry such as adapting teaching strategies based on using concrete models and technological tools. Therefore the review supported manipulation of physical models by students because it will help them to visualize atoms and molecules and promote long-term understanding.

Pedagogical content knowledge was defined in the literature as the most useful forms of content representation including the most powerful analogies, illustrations, examples, explanations, and demonstrations and the ways of representing and formulating the subject that makes it comprehensible to others. Hence the discussions of pedagogical content knowledge focused on the knowledge of what is typically difficult for students to learn, the representations that are most useful for teaching a specific subject matter.

According to the literature reviewed analogies, illustrations and examples explanations leads to teachers who can respond appropriately to students' questions, design activities involving an array of scientific representations and direct scientific discourse in the classroom. Also, if we do not blend content with the teaching process effectively, then the growth of students' scientific reasoning and problem solving skills will be stunted in the classroom.

The Senior High School chemistry curriculum with regard to chemical formulae and chemical equations is a progression of the concepts in the Junior High School science curriculum and therefore it is expected that students would get a better understanding of the two topics at the Senior High School level.

However, the Chief Examiners' (CE) reports for chemistry available at the West African Examinations Council (WAEC) have consistently reported on students' difficulty in writing correct chemical formulae and chemical equations. The literature indicated that some of the reasons behind students' difficulty commented on by chemistry Chief Examiners' are that: students do not understand the meaning of Roman numerals that are put in brackets of IUPAC names of compounds; students have problem with what valencies are and do not understand the role they play in writing of chemical formulae; students cannot write the correct names and formulae of some radicals; tetraoxophosphate (V) ion and the nitride ion are not familiar to the students and combination of some cations and anions to form neutral compounds is a problem to the students.

CHAPTER THREE

RESEARCH METHODS

This chapter provides a description of the design used for this study, instruments used for data collection, procedure used for data collection and method used to analyse the data collected.

Research Design

The two main research designs used in this study were cross-sectional survey and one group pre-test-post-test experimental design. The study was in three parts and followed a mixed method design using both quantitative and qualitative techniques. In the first part, six SHS classes (three SHS 1 and three SHS 2) from six different schools were pre-tested on writing of chemical formulae and chemical equations of inorganic compounds. The average scores of the classes were used as the unit of analysis. The best class and the worst class in the test were thus selected. All the senior high schools in the accessible population were also visited and all the SHS chemistry teachers on hand were given open ended questionnaires. The questionnaires centered on what the chemistry teachers considered as central ideas to writing of chemical formulae and chemical equations, the difficulties/limitations connected with teaching these two topics, difficulties/limitations connected with learning these two topics, the teaching procedures they use to help their students understand the two topics and how they ascertain students understanding of the two topics. Hence cross-sectional survey was employed to achieve this.

In the second part of the study, the one group pre-test-post-test experimental design was applied separately to the best and the worst classes selected in the pre-test in order to develop the teaching and learning material. The design used quantitative method to follow how the two classes abandon their alternative conceptions and misconceptions and how their conceptions changed as they were taken through series of lessons using the teaching and learning material for teaching chemical formulae and chemical equations. A comparative quantitative design was used to test hypotheses on students' scores in the pre-test and their scores in the last post-test and the magnitude of the difference was also computed.

In the last part of the study, another SHS 1 class which had not been taught at the time of the study was randomly selected from the accessible population and was used to validate the teaching and learning material which was previously developed. This new class was also pre-tested and taught with the already developed teaching and learning material for four weeks. Again, quantitative method was used to follow how the conceptions of this new class changed as they were taken through series of lessons using the developed teaching and learning material. Again, a comparative quantitative design was used to test hypotheses on the students' scores in the pre-test and their scores in the last post-test (post-test 3) and the magnitude of the difference was also computed.

Participants used in this study were not randomly assigned because that could have disrupted schedules or classes in the schools selected hence intact classes were used (Ary, Jacobs & Razavieh, 1990). The main weakness of this design is that it is inferior to randomized experiments in terms of internal validity (Trochim, 2000). However, the strength of this design in terms of threats to internal validity, is that this design is not affected by threats related to comparing groups (i.e., selection, treatments, regression, mortality, maturation, or interactions with selection).

Rationale for the research design

According to Ampiah (2004), research into educational issues has its own individual focus and therefore cannot divorce itself from quantitative and qualitative methodological issues that social science research raises. Also, Creswell and Plano Clark (2011) urges researchers to use a design that is best suited to their research problem. Both quantitative and qualitative methods were appropriate and necessary for this study in view of the nature of the research questions and hypotheses posed and the issues that required exploring. In this study, the mixed methods approach was found appropriate because it helped explain issues that could not be answered by only quantitative or qualitative approaches alone. Teachers' views regarding the teaching and learning of chemical formulae and chemical equations at the SHS level was sought and explained using qualitative approach. Selection of the two classes used for the development of the teaching and learning material after the pre-test was done through quantitative approach and changes in the students' conceptions as they were taken through series of lessons using the teaching and learning material was followed with a quantitative approach.

The mixed methods approach falls under the pragmatists' paradigm (Fraenkel, Wallen, & Hyun, 2012; Gray, 2009) which holds the view that knowledge is constructed based on the realities of our experience in the world as well as being socially constructed (Gray, 2009). This worldview is different from the positivists who believe that knowledge is objective and outside the world of the researcher and also different from the interpretivists who opine that knowledge is basically constructed. The pragmatic worldview takes a midway between the two extreme worldviews of quantitative and qualitative paradigms. Pragmatists believe that the duty of the researcher is to use whatever works (within the realms of academic rigor and appropriateness) to conduct their research (Fraenkel et al., 2012) which therefore presupposes that the researcher should look out for methods that will help them answer their research question(s) rather than being dogmatic (Fraenkel et al., 2012; Gray, 2009).

Despite the obvious advantages of integrating quantitative and qualitative data in this study, the two methods are based on different assumptions. It is therefore possible that such different research techniques could produce different results. This is a weakness in the use of this design.

Population

The population for this study was all the 1,800 SHS 1 science students, 1,630 SHS 2 science students and 42 chemistry teachers in all the 10 Senior High Schools offering the General Science programme in the Cape Coast Metropolis in the 2012/2013 academic year.

Sampling Procedure

Six SHS schools were selected from the population of 10 schools by simple random sampling using computer generated random numbers. In three of the schools sampled, there were 20 SHS 1 classes out of which three were selected by simple random sampling. In the other three schools sampled, there were also 12 SHS 2 classes and from these three were selected by simple random sampling. Hence in all, three SHS 1 science classes and three SHS 2 science classes were selected for the study. The sample comprised of 98 SHS 1 science students with 38 boys and 60 girls, 99 SHS 2 science students comprising of 84 boys and 15 girls. The mean age of the SHS 1 students was 16.9 years with standard deviation of 1.4 and the mean age of the SHS 2 students was 17.0 years with standard deviation of 1.2. The classes selected were labeled A, B and C for both levels (see Tables 18-22). All the students in the six classes selected who were available at the time of the study took part in the pre-test on chemical formulae and chemical equations. The sample also comprised of 20 SHS chemistry teachers selected by simple random sampling from a population of 42 chemistry teachers. The performances of the six classes selected in the pre-test are shown in tables 18, 19, 20, 21 and 22.

Table 18-*Means/Standard Deviations of the Performance of SHS 2 Classes in the Pre-test on Writing of Chemical Formulae*

	SHS 2 Classes					
	A (N = 36)		B (N = 33)		C (N = 30)	
Questions	Mean	SD	Mean	SD	Mean	SD
a. (1 – 9)	2.54	4.01	2.19	3.77	2.72	3.95
b. (1 – 9)	1.87	3.75	1.71	3.47	1.63	3.42
c. (1 – 9)	0.57	2.04	0.39	1.46	0.46	1.71
d. (1 – 9)	0.57	2.04	0.39	1.46	0.46	1.71
e. (1 – 9)	1.30	2.90	2.07	3.76	2.57	4.00

Table 19-*Means/Standard Deviations of the Performance of SHS 1 Classes in the Pre-test on Writing of Chemical Formulae*

	SHS 1 Classes					
	A (N = 25)		B (N = 38)		C (N = 35)	
Questions	Mean	SD	Mean	SD	Mean	SD
a. (1 – 9)	2.20	3.78	1.35	2.95	2.20	3.60
b. (1 – 9)	5.92	7.17	3.78	6.33	5.31	6.33
c. (1 – 9)	1.84	4.28	1.35	4.25	1.33	3.63
d. (1 – 9)	1.92	3.20	0.17	1.01	0.51	2.02
e. (1 – 9)	3.84	6.14	2.73	5.80	3.17	6.36

Table 20-*Means/Standard Deviations of the Performance of SHS 2 Classes in the Pre-test on Writing of Chemical Equations*

	SHS 2 Classes					
	A (N = 36)		B (N = 33)		C (N = 30)	
Questions	Mean	SD	Mean	SD	Mean	SD
1.	0.21	0.41	0.29	0.46	0.42	0.50
2.	0.17	0.38	0.16	0.37	0.31	0.47
3.	0.07	0.26	0.19	0.40	0.12	0.33
4.	0.21	0.41	0.32	0.48	0.35	0.49
5.	0.07	0.26	0.13	0.34	0.12	0.33
6.	0.14	0.35	0.00	0.00	0.04	0.20

Table 21-*Means/Standard Deviations of the Performance of SHS 1 Classes in the Pre-test on Writing of Chemical Equations*

	SHS 1 Classes					
	A (N = 25)		B (N = 38)		C (N = 35)	
Questions	Mean	SD	Mean	SD	Mean	SD
1.	0.20	0.41	0.23	0.48	0.26	0.44
2.	0.20	0.41	0.16	0.37	0.31	0.47
3.	0.04	0.20	0.02	0.15	0.06	0.24
4.	0.36	0.49	0.25	0.49	0.31	0.47
5.	0.04	0.20	0.16	0.37	0.20	0.47
6.	0.00	0.00	0.05	0.21	0.14	0.36

Table 22-*Class Mean Scores of Pre-Test on Chemical Formulae and Chemical Equations for Both SHS 1 & 2 Classes*

	SHS 1 Classes			SHS 2 Classes		
	A	B	C	A	B	C
Tests	Mean	Mean	Mean	Mean	Mean	Mean
Formulae Writing	3.14	1.88	2.50	1.33	1.35	1.57
Equations Writing	0.14	0.15	0.20	0.15	0.18	0.23

From Tables 18-22, it is obvious that all the six classes that took part in the pre-test performed poorly in both the chemical formulae and the chemical equations pre-tests. From the mean scores of the classes in the tests, none of the six classes obtained even one-fourth of the overall mark in the chemical formulae test. The situation is no different in the chemical equations pre-test. However, SHS 1A obtained the relatively highest mean mark and SHS 2A obtained the least mean score. The two classes were thus chosen as the classes to use in developing the teaching and learning material. The two classes SHS 1A and SHS 2A were in two different senior high schools of about 15 km apart. The two classes were chosen so that their difficulties could help in producing a material that could be used to teach students with different ability levels.

Data Collection Instruments

Two major instruments were used in this study. They are: (1) Achievement tests and (2) Open-ended questionnaires. Five achievement tests were used in this study. They are:

(a) Pre-test on chemical formulae and chemical equations.

(b) Post-test 1 on chemical formulae and chemical equations

(c) Post-test 2 on chemical formulae and chemical equations

(d) Post-test 3 on chemical formulae and chemical equations and

(e) Validation post-test on chemical formulae and chemical equations

Pre-test on chemical formulae

The chemical formulae pre-test consisted of the IUPAC names of nine inorganic compounds: iron (III) trixoxocarbonate (IV), silver nitride, iron (III) tetraoxosulphate (VI), ammonium trioxocarbonate (IV), lithium trioxocarbonate (IV), aluminium tetraoxosulphate (VI), copper (II) tetraoxophosphate (V), calcium tetraoxophosphate (V) and ammonium sulphide (see Appendix A).

The items in the chemical formulae pre-test were constructed by the researcher using the prescribed SHS chemistry textbooks and chemistry syllabus for 2010. Students were expected to write the formula of each compound, write the constituent ions that formed each compound, write the subscripts of the ions in each compound, explain the meaning of those subscripts if there were any and write the valency of each constituent ion in the compound. In all, the chemical formulae pre-test consisted of 45 items and each item carried one mark.

Pre-test on chemical equations

The chemical equations pre-test also consisted of six chemical reactions in statement form. Two of the reactions were combination reactions, two were displacement reactions and two were metathesis reactions. The items were: aluminium metal ion reacts with fluoride ion to form aluminium fluoride; iron (II) metal ion reacts with fluoride ion to form iron (II) fluoride; potassium hydroxide reacts with tetraoxophosphate (V) acid to form; potassium tetraoxophosphate (V) and water; sodium oxide reacts with trioxonitrate (V) acid to form sodium trioxonitrate (V) and water; copper (II) metal reacts with silver trioxonitrate (V) to form copper (II) trioxonitrate (V) and silver metal and potassium tetraoxochromate (VI) reacts with lead trioxonitrate (V) to form lead tetraoxochromate (VII) and potassium trioxonitrate (V) (see Appendix B).

The items in the chemical equations pre-test were also constructed by the researcher using the prescribed SHS chemistry textbooks and chemistry syllabus for 2010. Students were therefore expected to translate these statement reactions into balanced equations in symbols. Each correct balanced equation in symbol carried 1 mark hence the chemical equations pre-test carried a total of 6 marks.

By way of validation, the chemical formulae and chemical equations pre-tests were shown to two chemistry lecturers in the Department of Science Education, University of Cape Coast and my team of supervisors. After this stage, the chemical formulae and chemical equations pre-tests were pilot-tested using an intact class of 50 SHS 2 elective science students selected from a school in the population but which did not take part in the main study. The mean age of the students was 17.9 years with standard deviation of 1.3. The test was not timed and students submitted their work as and when they completed it. Each question in both tests carried 1 mark and the total mark for the chemical formulae pre-test was 45 marks and that for the chemical equations pre-test was 6 marks. The coefficient of reliability of the chemical formulae and chemical equations pre-tests were determined using the Kuder Richardson KR-20 formula. The KR-20 value of the coefficient of reliability for the chemical formulae pre-test was 1.0 and that for chemical equations pre-test was 0.96. The difficulty and discrimination indices of the items in the two pre-tests were also calculated (see Appendices Q and R).

Post-test 1 on chemical formulae

Chemical formulae post-test 1 was an equivalent form of the chemical formulae pre-test. The items in the Chemical formulae post-test 1 were: potassium tetraoxochromate (VI), copper (II) trioxonitrate (V), iron (II) nitride, calcium heptaoxodichromate (VI), lithium trioxochlorate (V), barium tetraoxomanganate (VII), aluminium sulphide, mercury (I) oxide, beryllium hydroxide (see Appendix C). Chemical formulae post-test 1 requested students to perform the same task as in Chemical formulae pre-test.

Post-test 1 on chemical equations

Chemical equations post-test 1 was an equivalent form of the chemical equations pre-test. The items in the Chemical equations post-test 1 were: silver metal ion reacts with nitride ion to form silver nitride, zinc metal ion reacts with sulphide ion to form Zinc sulphide, calcium hydroxide reacts with trioxonitrate

(V) acid to form calcium trioxonitrate (V) and water, aluminium oxide reacts with hydrochloric acid to form aluminium chloride and water, magnesium metal ion reacts with tetraoxosulphate (VI) acid to form magnesium tetraoxosulphate (VI) and hydrogen gas, barium metal ion reacts with trioxocarbonate (IV) acid to form barium trioxocarbonate (IV) and hydrogen gas (see Appendix D). The task performed by students in chemical equations post-test 1 was the same as in chemical equations pre-test.

Post-test 2 on chemical formulae

Chemical formulae post-test 2 was an equivalent form of the chemical formulae pre-test and post-test 1. The items in the Chemical formulae post-test 2 were: silver oxide, aluminium trioxosulphate (IV), ammonium trioxocarbonate (IV), zinc bromide barium tetraoxophosphate (V), copper (II) trioxosulphate (IV), iron (II) oxide, sodium trioxonitrate (V), lead (II) tetraoxosulphate (VI) (see Appendix E). The task performed by students in chemical formulae post-test 2 was the same as in chemical formulae pre-test and post-test 1.

Post-test 2 on chemical equations

Chemical equations post-test 2 was an equivalent form of the chemical equations pre-test and post-test 1. The items in the chemical equations post-test 2 were: potassium metal ion reacts with bromide ion to form potassium bromide, beryllium metal ion reacts with iodide ion to form beryllium iodide, magnesium oxide reacts with tetraoxophosphate (V) acid to form magnesium tetraoxophosphate (V) and water, lithium hydroxide reacts with trioxosulphate (IV) acid to form Lithium trioxosulphate (IV) and water, zinc metal ion reacts with silver trioxonitrate (V) to form zinc trioxonitrate (V) and silver metal, iron (II) metal ion reacts with copper (II) tetraoxosulphate (VI) to form iron (II) tetraoxosulphate (VI) and copper metal (see Appendix F). The task performed by students in chemical equations post-test 2 was the same as in chemical equations pre-test and post-test 1.

Post-test 3 on chemical formulae

Chemical formulae post-test 3 was also an equivalent form of the chemical formulae pre-test, post-test 1 and post-test 2. The items in the Chemical formulae post-test 3 were: lithium nitride, iron (III) sulphide, lead (II) trioxocarbonate (IV), ammonium tetraoxosulphate (VI), sodium trioxochlorate (V), copper (II) fluoride, beryllium hydroxide, iron (II) cyanide, zinc trioxocarbonate (IV) (see Appendix G). The task performed by students in chemical formulae post-test 3 was the same as in chemical formulae pre-test, post-test 1 and post-test 2.

Post-test 3 on chemical equations

Chemical equations post-test 3 was an equivalent form of the chemical equations pre-test, post-test 1 and post-test 2. The items in the chemical equations post-test 3 were: copper (II) metal ion reacts with tetraoxosulphate (VI) ion to form copper (II) tetraoxosulphate (VI), barium metal ion reacts with hydroxide ion to form barium hydroxide, potassium hydroxide reacts with trioxonitrate (V) acid to form potassium trioxonitrate (V) and water, calcium oxide reacts with tetraoxosulphate (VI) acid to form calcium tetraoxosulphate (VI) and water, sodium metal ion reacts with aluminium trioxonitrate (V) to form sodium trioxonitrate (V) and aluminium metal, calcium metal ion reacts with lead (II) tetraoxosulphate (VI) to form calcium tetraoxosulphate (VI) and lead metal (see Appendix H). The task performed by students in chemical equations post-test 3 was also the same as in chemical equations pre-test, post-test 1 and post-test 3.

Open ended questionnaire

Two open ended questionnaires one on writing of chemical formulae and the other on writing of chemical equations were used in this study. Both questionnaires consisted of five main items (see Appendices O and P). The two questionnaires sought to find out the following from SHS chemistry teachers:

(1) what the teachers consider as central ideas to writing chemical formulae and chemical equations of inorganic compounds,

(2) the difficulties/limitations connected with teaching these two topics,

(3) the difficulties/limitations connected with learning these two topics,

(4) the teaching procedures they use to help their students understand the two topics and

(5) how they ascertain students understanding/confusion of the two topics.

The items in the open ended questionnaire were constructed by the researcher after which they were shown to my team of supervisors and two SHS chemistry teachers for them to validate the items.

Data Collection Procedure

Data collection took place from September, 2012 to December, 2012. Permission was sought from the headmasters/headmistresses of the selected senior high schools to conduct the research in their schools. Consent was also sought from the heads of science departments and the chemistry teachers of the schools selected. The students were also briefed about the purpose of the study. The researcher administered the pre-test to the classes in their various schools. The pre-test was not timed and students submitted their scripts as and when they completed them. Six classes (3 SHS 1 and 3 SHS 2) from six different schools took the pre-test. All the six classes performed poorly at the pre-test however, the class that did relatively well and the weakest class were selected for the study. The two classes selected: SHS 1A and SHS 2A from 2 different schools were used for the development of the teaching and learning material.

A week after the pre-test was administered, the researcher returned to the selected classes SHS 1A and SHS 2A in their individual schools and distributed their marked scripts to them and explained to them how the research was going to be carried out.

In the third week, teaching to develop the teaching and learning material started and the two classes were taught separately in their schools. In lesson 1, students were introduced into the writing of formulae of cations, anions, radicals and inorganic acids and explanation of certain terminologies critical to formulae writing were discussed with students. In lesson 2, students were taught how to identify ions in an ionic compound and there was discussion on how to combine the ions to form neutral compounds. Using marker board illustrations and various examples, students were taught how to write chemical formulae (part 1). In lesson 3, marker board illustrations were again used to teach students how to write combination, displacement and metathesis reactions (part 1).

In lesson four (1st iteration), the teaching and learning material was used to teach the students. The teaching and learning material was made of wood, shaped differently and painted with different colours to represent cations and anions. The teaching and learning material was used to teach the students how to combine cations and anions, how to use it to write chemical formulae of inorganic compounds (part 2) and how to use it to write combination, displacement and metathesis reactions (part 2).

In lesson five (2nd iteration) charts of the periodic table were prepared by the researcher and given to individual students and the teaching and learning material was used to teach the students how to write chemical formulae and chemical equations of inorganic compounds using different compounds.

Finally, in lesson six (3rd iteration) charts on how to assign oxidation numbers were prepared by the researcher in addition to the periodic tables and given to individual students and the teaching and learning material was used to teach the two classes how to write chemical formulae and chemical equations of inorganic compounds using different compounds.

In all, eight weeks were used for pre-test administration and development of teaching and learning material. The breakdown is as follows: first two weeks were used for pre-test administration, discussion of results and orientation of students for the study. In the next three weeks, students were introduced to basic concepts critical to writing of chemical formulae and chemical equations of inorganic compounds. In the remaining three weeks, students were taken through three iterations in the development of the teaching and learning material. Three iterations were used because the researcher was satisfied with students' progressive performance.

At the end of each iteration, each class took a post-test on writing of chemical formulae and chemical equations separately in their schools but same items for both classes.

After the teaching and learning material was developed, it was validated using another SHS 1 class which had not been taught the two topics at the time the study was conducted. This new SHS 1 class was selected from the population using the simple random sampling technique. In the first week of validation, the class was pre-tested with the same pre-test items used in the previous stage. After the pre-test, this validation class was also taught with the already developed teaching and learning material for four weeks. Students were given the fifth week to revise and a validation post-test was administered in the sixth week.

In the administration of the open-ended questionnaire, 20 SHS chemistry teachers were selected from the population using simple random sampling. Each teacher selected was given two open-ended questionnaires; one on writing of chemical formulae and the other on writing of chemical equations. Hence in all, 40 questionnaires (20 for each topic) were given out. The researcher returned to the schools after two weeks to collect the questionnaires and all 40 questionnaires given out were received.

Data Processing and Analysis

Qualitative data gathered from the open-ended questionnaire in research question 1 was analysed using thematic content analysis. The two questionnaires centered on five key areas of teaching and learning of chemical formulae and chemical equations and each key area was used as theme. The initial difficulties SHS 1A and SHS 2A science students had on the writing of chemical formulae and chemical equations in research question 2 and performances of SHS 1A and SHS 2A science students in the various post-tests during development of the teaching and learning material in research question 3 as well as performance of the validation SHS 1 science students in the pre-test and post-test during validation of the teaching and learning material already developed in research question 4 were analysed using means, standard deviations and proportion expressed in percentages. The mean mark was used because in computing it for a particular test, every student's score in the test was used hence it gave the best summary score and provided the direction of performance. The standard deviation was also used because it used every student's score in the test and provided the average of the individual amounts of variability in the test scores.

Changes in students' conceptions in hypotheses 1, 2, 3, 4, 5 and 6 were analysed using the McNemar chi square test for significance of change. McNemar Chi-Square test for significance of change was used because it has the ability to determine the degree of changes in students' conceptions from the pre-test to the post-tests. To determine the degree of change in students' conceptions from the pre-test to the post-test 3, the McNemar chi square test for significance of changes was used. To do this, a fourfold table of frequencies was set up to represent the pre-test and post-tests responses from the students. The features of the table are illustrated in Figure 3, in which positive (+) and negative (–) signs are used to signify the different responses given by students.

		After -	After +
Before	+	A	B
	-	C	D

Figure 3: Fourfold table used in testing significance of change

The – sign means presence of alternative conception before or after intervention and the + sign means there is no alternative conception before or after intervention. A student is tailed in cell 'A' if there is a change in conception from + to – and tailed in cell 'D' if there is a change from – to +. This means change in conception before and after intervention occurs only in cells 'A' and 'D'. If there is no change in conception, the student is tailed in cell 'B' if the response is + both before and after intervention and tailed in cell 'C' if the response is – both before and after intervention. From these, the McNemar formula is given by

$$\chi^2 = \frac{(|A - D| - 1)^2}{A + D}$$

With df = 1

This formula was used to calculate the degree of change in students' alternative conceptions from pre-test to the post-test 1, from post-test 1 to the post-test 2 and from post-test 2 to the post-test 3. For an observed critical value for equal to or greater than 3.84 at $\alpha = .05$ for a particular significance level of $df = 1$, the implication is that a significant effect has taken place after the intervention.

Null hypotheses 7, 8, 9, 10, 11 and 12 were tested with paired samples t-test to check whether there was any statistically significant difference in the mean scores of the pre-test of SHS 1A, SHS 2A and validation SHS 1 classes and their post-tests results. The effect sizes were also computed to ascertain the magnitude of the differences.

Lesson Plans used for Teaching during Development of the Teaching and Learning Material

In all, six lesson plans were used in the development of the teaching and learning material. Lessons 1-3 were used to introduce the students to the basic concepts they need before the teaching and learning material is used to teach them. Hence in using the teaching and learning material developed in this study, one must always go through lessons 1-3 before using the teaching and learning material. Lessons 4-6 were used in the iterations stage in the course of developing the teaching and learning material.

LESSON ONE

Topic: Writing the Formulae of Cations, Anions, Radicals and Inorganic Acids

Duration: 40 minutes

Relevant Previous Knowledge: In JHS, students were taught symbols of first 20 elements of the periodic table, how positive and negative charges are formed, metals and non-metals and their properties and chemical formulae of simple binary compounds.

Specific Objectives

By the end of the lesson the student should be able to:

1. distinguish between a binary and a ternary compound
2. write the formulae of some common cations, anions and radicals

Teaching/Learning materials: Boardmarker, duster.

Advanced Preparation: Teacher makes all teaching and learning materials ready for the lesson.

STAGE/ESTIMATED TIME	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
INTRODUCTION (5min)	Teacher uses question and answer technique to review students' previous knowledge as shown below: **QUESTION:** 1. From the periodic table, give the names and symbols of 3 elements each of (a) Group I (b) Group II and (c) Group VII	Students listen to the question and answer as follows: 1. (a) Lithium- Li, Sodium- Na and Potassium-K (b) Beryllium-Be, Magnesium-Mg and Calcium- Ca (c) Fluorine-F, Chlorine-Cl and	

	2. Give two properties of each group of elements	Bromine- Br 2. (a) i. They exhibit a constant oxidation state of +1 in all their compounds ii. They are metallic and therefore are good conductors of electricity and heat (b) (i) They exhibit a constant oxidation state of +2 in all their compounds	

		ii. They are harder and so have high melting and boiling points (c) i. They are non-metals and insulators ii. They are strongly electronegative	

STAGE/ESTIMATED TIME	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
CONTENT DEVELOPMENT STEP 1 **Explanation of Terminologies Critical to Formulae Writing** 30 minutes	Teacher uses discussion method to explain the terminologies to students	Students pay attention and follow the discussion	1. Binary Compound: They are compounds that contain atoms of two different elements only. Examples are copper (II) oxide (CuO), sodium chloride (NaCl), hydrogen chloride (HCl), magnesium oxide (MgO), aluminium chloride ($AlCl_3$), iron (II) sulphide, (FeS) etc. 2. Ternary Compounds: They are compounds that contain atoms of three different elements. Examples are iron (II) nitrate – $Fe(NO_3)_2$, ammonium sulphide - $(NH_4)_2S$ Ammonium hydroxide - NH_4OH, tetraoxosulphate

			(VI) acid- H_2SO_4, tetraoxophosphate (V) acid- H_3PO_4 etc 3. **Ion and Valency**: An ion is a charged atom or charged group of atoms. Three types of ions will be discussed: (a) cations (b) simple anions and (c) radicals or complex ions (a) **CATIONS**: A cation is a positively charged atom formed by the lose of an electron or lose of electrons. All the group I metals have constant oxidation state of +1. This

			means that in forming ionic bond with electronegative elements, the metals prefer losing their one valence electron to the electronegative element to achieve a stable electronic configuration. So the ionic form of some of the group I metals is as shown below: Li = Li^+ ; Na = Na^+ ; K = K^+ ; Rb = Rb^+ etc **Valency** is the combining number of an element. It is the same as oxidation number except that it has no charge. Therefore all the group I metals have valency of 1. Likewise, metals of groups II have oxidation states of +2 because in forming ionic bonds with

			electronegative elements, they prefer giving out their 2 valence electrons to achieve stable configuration. Hence metals of groups II have valency of 2. Examples of the ionic form of group II metals are: Be = Be^{2+} ; Mg = Mg^{2+} ; Ca = Ca^{2+} etc. With the exception of Al all the group III elements are semi-metals that is, they partially behave as metals and sometimes as non-metals. Therefore Al in forming ionic compounds prefer giving out its 3 valence electrons and so it has valency of 3. Its ionic form is Al = Al^{3+}

			For metals with more than one oxidation number, the oxidation number is placed in parenthesis in capital Roman numerals. Examples iron(III) ion = Fe^{3+}, Copper(II) ion = Cu^{2+}, Lead(II) ion = Pb^{2+} etc **(b) Anions** An anion is a negatively charged atom formed by the gain of an electron or gain of electrons. For monatomic anions, the charge is equivalent to the group number -8. For instance, the group VII elements have oxidation state of -1 and exist in ionic form as: F = F^- ; Cl = Cl^- ; Br = Br^- ; I = I^-

			Oxygen is found in group VIA and so has oxidation number of -2 **(c) Radicals or Complex ions** Radicals are ions which contain two or more atoms chemically bonded together. Examples of common radicals and their names are shown in the table below:

STAGE/ ESTIMATED TIME	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS	
			Radicals	**IUPAC Names**
			NO_3^-	trioxonitrate (V) ion
			NO_2^-	dioxonitrate (III) ion
			ClO^-	oxochlorate (I) ion
			ClO_3^-	trioxochlorate (V) ion
			ClO_4^-	tetraoxochlorate (VII) ion
			CrO_4^{2-}	tetraoxochromate (VI) ion
			MnO_4^-	tetraoxomanganate (VII) ion
			SO_4^{2-}	tetraoxosulphate (VI) ion
			PO_4^{3-}	tetraoxophosphate (V) ion
			HPO_4^{2-}	hydrogen tetraoxophosphate (V) ion

			HSO_4^-	hydrogen tetraoxosulphate (VI) ion
			SO_3^{2-}	trioxosulphate(IV) ion
			NH_4^+	ammonium ion
			SO_4^{2-}	tetraoxosulphate(VI) ion
			OH^-	hydroxide ion
			CO_3^{2-}	trioxocarbonate (IV) ion
			HCO_3^-	hydrogen trioxocarbonate(IV) ion
			Cations	**Names**
			Li^+	lithium ion
			K^+	potassium ion
			Na^+	sodium ion
			Cu^+	copper(I) ion
			Cu^{2+}	copper(II) ion

			Zn^{2+}	zinc ion
			Al^{3+}	aluminium ion
			Mn^{2+}	manganese(II) ion
			Pb^{2+}	lead(II) ion
			Cr^{3+}	chromium(III) ion
			Cr^{2+}	chromium(II) ion
			H^{+}	hydrogen ion
			H_3O^{+}	hydroxonium ion
			NH_4^{+}	ammonium ion
			Be^{2+}	beryllium ion
			Mg^{2+}	magnesium ion
			Ca^{2+}	calcium ion

			Zn^{2+}	zinc ion
			Al^{3+}	aluminium ion
			Mn^{2+}	manganese(II) ion
			Pb^{2+}	lead(II) ion
			Cr^{3+}	chromium(III) ion
			Cr^{2+}	chromium(II) ion
			H^{+}	hydrogen ion
			H_3O^{+}	hydroxonium ion
			NH_4^{+}	ammonium ion
			Be^{2+}	beryllium ion
			Mg^{2+}	magnesium ion
			Ca^{2+}	calcium ion

			Inorganic acids	**Names**
			HNO_2	dioxonitrate (III) acid
			HNO_3	trioxonitrate (V) acid
			HClO	oxochlorate (I) acid
			H_2SO_4	tetraoxosulphate (VI) acid
			H_3PO_4	tetraoxophosphate (V) acid
			H_2SO_3	trioxosulphate (IV) acid
CLOSURE 5 minutes	Teacher uses question and answer strategy to review the lesson.	Students listen to the questions and answer them accordingly.		

REFERENCE: Ameyibor, K., & Wiredu, M.B. (1991). *Chemistry for senior secondary schools.* Accra: Unimax Macmillan.

LESSON TWO

Topic: Writing of Chemical Formulae of Inorganic Compounds

Duration: 40 minutes

Relevant Previous Knowledge: In the previous lesson, students were taught the ionic formulae of various metal ions, anions and radicals.

Specific Objectives

By the end of the lesson the student should be able to:

1. identify the ions in an ionic compound
2. combine cations and anions to form neutral compounds
3. write the chemical formulae of inorganic compounds

Teaching/Learning materials: Duster, white boardmarker.

STAGE/ESTIMATED TIME	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
INTRODUCTION (5min)	Teacher uses question and answer technique to review students' previous knowledge as shown below: **QUESTION:** Write the formulae of the following ions: 1. potassium ion 2. manganese (II) ion 3. chromium (III) ion 4. zinc ion	Students pay attention and answer the questions. K^+ Mn^{2+} Cr^{3+} Zn^{2+}	

	5. tetraoxomanganate (VII) ion 6. tetraoxosulphate (VI) ion	MnO_4^- SO_4^{2-}	
CONTENT DEVELOPMENT **STEP 1** **Identification of ions in Ionic Compounds** 10 minutes	Teacher uses question and answer strategy together with discussion method to help students identify the ions in ionic compounds. **QUESTION** Write the cations and anions in the following ionic compounds: a. sodium oxide	Students look at the tables of ions given to them and answer the questions as follows: a. Na^+ and O^{2-}	

	b. aluminium oxide	b. Al^{3+} and O^{2-}	
	c. copper(I) oxide	c. Cu^{+} and O^{2-}	
	d. iron(III) chloride	d. Fe^{3+} and Cl^{-}	
	e. lead(II) bromide	e. Pb^{2+} and Br^{-}	
	f. calcium hydroxide	f. Ca^{2+} and OH^{-}	
	g. lead(II) trioxonitrate(V)	g. Pb^{2+} and NO_3^{-}	
	h. sodium trioxocarbonate (IV)	h. Na^{+} and CO_3^{2-}	
	i. aluminium trioxonitrate(V)	i. Al^{3+} and NO_3^{-}	
	j. iron(II) tetraoxo	j. Fe^{2+} and SO_4^{2-}	

	sulphate (VI) Teacher asks all the students to look at the tables of ions they were given in the previous lesson to answer the questions. Teacher also hints students to note that the symbol of the **metal ion is always written first** before the symbols of non-metal ions or radicals are written.		

CONTENT DEVELOPMENT STEP 2 **Combination of Ions to form Neutral Ionic Compounds** 20 minutes	Teacher uses discussion method together with question and answer strategy to assist students to combine the ions they have identified to form neutral ionic compounds. Teacher now demonstrate on the chalkboard for students to see.	Students pay attention, listen and answer any question teacher may ask	**a. sodium oxide** Na^{+} and O^{2-} Valency of Na = 1 Valency of O = 2 So we need 2 atoms of Na to balance O. Therefore 2 atoms of Na will combine with 1 atom of O. Hence the formula is **Na_2O** **b. aluminium oxide** Al^{3+} and O^{2-}

			Valency of Al = 3 Valency of O = 2 So we need 2 atoms of Al and 3 atoms of O in order to balance. Therefore 2 atoms of Al will combine with 3 atoms of O. Hence the formula is **Al_2O_3** **c. copper(I) oxide** Cu^{+} and O^{2-} Valency of Cu = 1 Valency of O = 2 So we need 2 atoms of Cu to

			balance O. Therefore 2 atoms of Cu will combine with 1 atom of O. Hence the formula is **Cu_2O** **d. iron(III) chloride** Fe^{3+} and Cl^- Valency of Fe = 3 Valency of Cl = 1 So we need 3 atoms of Cl to balance Fe. Therefore 1 atom of Fe will combine with 3 atoms of Cl. Hence the formula is **$FeCl_3$** **e. lead(II) bromide**

			Pb^{2+} and Br^{-} Valency of Pb = 2 Valency of Br = 1 So we need 2 atoms of Br to balance Pb. Therefore 1 atom of Pb will combine with 2 atoms of Br. Hence the formula is **$PbBr_2$** **f. calcium hydroxide** Ca^{2+} and OH^{-} Valency of Ca = 2 Valency of OH = 1 So we need 2 of OH to balance Ca. Therefore 1 atom

			of Ca will combine with 2 of OH. Since OH is a radical it must be put in a bracket so that both the O and the H will all be multiplied by 2. Hence the formula is **$Ca(OH)_2$** **g. lead(II) trioxonitrate(V)** Pb^{2+} and NO_3^- Valency of Pb = 2 Valency of NO_3 = 1 So we need 2 of NO_3 which is also a radical to balance Pb. Therefore 1 atom of Pb will

			combine with 2 of NO_3. Since NO_3 is a radical it must be put in a bracket and multiplied by 2. Hence the formula is **$Pb(NO_3)_2$** **h. sodium trioxocarbonate(IV)** Na^+ and CO_3^{2-} Valency of Na = 1 Valency of CO_3 = 2 So we need 2 atoms of Na to balance the radical CO_3. Therefore 2 atoms of Na will combine with 1 radical of CO_3.

			Hence the formula is $\mathbf{Na_2CO_3}$ **i. aluminium trioxonitrate(V)** Al^{3+} and NO_3^- Valency of Al = 3 Valency of NO_3 = 1 So we need 3 of the radical NO_3 to balance the Al. Therefore 3 of NO_3 will combine with 1 atom of Al. Hence the formula is $\mathbf{Al(NO_3)_3}$ j.

			iron(II) tetraoxosulphate(VI) Fe^{2+} and SO_4^{2-} Valency of Fe = 2 Valency of SO_4^{2-} = 2 Since the valencies are the same, it means that we need 1 atom of Fe and 1 SO_4 radical. Therefore the formula is **$FeSO_4$**

CLOSURE 5 minutes	Teacher uses question and answer strategy to review the lesson and to find out whether students understood what was taught and whether the lesson objectives were achieved after which assignment will be given to the students.	Students listen to the questions and answer them accordingly.	

REFERENCE:

Ameyibor, K. & Wiredu, M.B. (1991). *Chemistry for senior secondary schools.* Accra: Unimax Macmillan.

LESSON THREE

Topic: Writing of Chemical Equations of Inorganic Reactions

Sub Topic: Combination, Displacement and metathesis Reactions

Duration: 40 minutes

Relevant Previous Knowledge:

Students have been taught how to write the chemical formulae of inorganic compounds.

Specific Objectives

By the end of the lesson the student should be able to write chemical equations of:

1. combination reaction
2. displacement reaction and
3. metathesis reaction

Teaching/Learning materials: Duster, boardmarker.

STAGE/ESTIMATED TIME	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
INTRODUCTION (5min)	Teacher uses question and answer technique to review students'previous knowledge as shown below: **QUESTION:** Write the chemical formulae of the following compounds: a. Iron (II) sulphide b. Ammonium trioxocarbonate (IV) c. Lithium tetraoxochlorate (VII)	Students answer the questions as shown below: a. FeS b. $(NH_4)_2CO_3$ c. $LiClO_4$	

	d. Aluminium tetraoxosulphate (VI) e. Silver nitride	d. $Al_2(SO_4)_3$ e. Ag_3N	
CONTENT DEVELOPMENT **STEP 1** **Writing of Chemical Equations of Combination, Displacement and Metathesis Reactions**	Teacher uses discussion method to help students understand writing of chemical equations. Teacher tells students to note that the principle used in combining ions will also be used here.	Students listen carefully, take part in the discussion and take note of what teacher will say.	**Combination Reaction** Combination reaction is any reaction in which two or more substances combine to form a single product. The general form of a combination reaction is $A + B \longrightarrow AB$ Examples are Reaction between iron(II) ion and sulphide ion to form iron(II) sulphide $Fe^{2+} + S^{2-} \longrightarrow FeS$

30 minutes			Reaction between aluminium ion and oxide ion to form aluminium oxide $Al^{3+} + O^{2-} \longrightarrow Al_2O_3$ In arriving at the formulae of the product, the procedure used in the writing of chemical formulae is applied here. **Displacement Reaction** A displacement reaction involves an element reacting with a compound whereby the element displaces a second element from the compound. The general form of this type of reaction is: $A + BC \rightarrow AC + B$ The various types are discussed below: **a. An active metal + an acid**

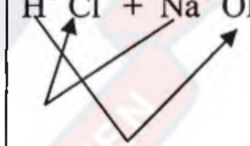
			Examples are: 1. Reaction between Zinc metal and hydrochloric acid to form zinc chloride and hydrogen gas Zn^{2+} + $2H^+ Cl^-$ = $ZnCl_2$ + $(2H^+ + 2e- = H_2)$ Hence the **equation** is $Zn + 2HCl \longrightarrow ZnCl_2 + H_2$ 2. Reaction between magnesium metal and tetraoxosulphate(VI) acid to form magnesium tetraoxosulphate(VI) and hydrogen gas Mg^{2+} + $2H^+ SO_4^{2-}$ = $MgSO_4$ + $(2H^+ + 2e^- = H_2)$

			Hence the **equation** is $Mg + H_2SO_4 \longrightarrow MgSO_4 + H_2$ **b. A metal + a salt** Examples are: 1. Reaction between copper (II) metal and silver trioxonitrate(V) to form copper(II) trioxonitrate(V) and silver metal $Cu^{2+} + Ag^{+}NO_3^{-} = Cu(NO_3)_2 + (Ag^{+} + e^{-})$ Hence the **equation** is $Cu + 2AgNO_3 \longrightarrow Cu(NO_3)_2 + 2\ Ag$

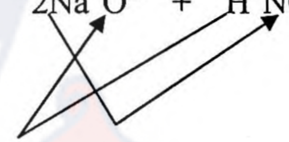
			2. Reaction between iron(II) metal and copper(II) tetraoxosulphate(VI) to form Iron(II) tetraoxosulphate(VI) and copper(II) metal Fe^{2+} + Cu^{2+} SO_4^{2-} = $FeSO_4$ + (Cu^{2+} + $2e^-$ = Cu) Hence the equation is Fe + CuSO4 ⟶ FeSO4 + Cu **Metathesis Reaction** A metathesis is a double displacement reaction that usually occurs in water solution. The general form of a metathesis reaction is:

			AB + CD → AD + CB **Types of Metathesis Reactions:** **a. Precipitation Reactions** In this type of reaction, two compounds which are water soluble react to form two new compounds, one of which is a precipitate (i.e. insoluble in water). The precipitate is often indicated by an arrow pointing downward, ↓, written next to its formula. Examples are 1. Reaction between silver nitrate and sodium chloride to form silver chloride and sodium nitrate

			$Ag^{+}NO_3^{-}$ + $Na^{+}Cl^{-}$ = AgCl + $NaNO_3$ Hence the **equation** is $AgNO_3$ + NaCl ⟶ AgCl↓ + $NaNO_3$ 2. Reaction between barium chloride and potassium sulphate to form barium sulphate and potassium chloride $Ba^{2+}Cl^{-}$ + $K^{+}SO_4^{2-}$ = $BaSO_4$ + KCl Hence the **equation** is $BaCl_2$ + K_2SO_4 ⟶ $BaSO_4$↓ + 2KCl

			b. Neutralization Reactions (sometimes called acid-base reactions) A neutralization reaction occurs between an acidic compound and a basic compound to form salt and water. **1. Reaction between an acid and a base** Examples are: 1. Reaction between hydrochloric acid and sodium hyroxide $H^+ Cl^- + Na^+ OH^- = NaCl + H_2O$  Hence the reaction is as shown below $HCl + NaOH \longrightarrow NaCl + H_2O$ 2. Reaction between tetraoxosulphate (VI) acid

			and magnesium hydroxide $2H^{+}\ SO_4^{2-} + Mg^{2+}\ 2OH^{-} = MgSO_4 + H_2O$ Hence the reaction is $H_2SO_4 + Mg(OH)_2 \longrightarrow MgSO4 + H2O$ **2. Reaction between a metal oxide and an acid.** When oxides of many metals are added to water, bases are formed. $CaO + H_2O \rightarrow Ca(OH)_2$ Generally, these metal oxides are called basic anhydrides and they act like bases when mixed with acids. Examples are: 1. Reaction between calcium oxide and

			hydrochloric acid $Ca^{2+}O^{2-} + H^{+}Cl^{-} = CaCl_2 + H_2O$  So the equation is as shown below $CaO + 2HCl \longrightarrow CaCl_2 + H_2O$ 2. Reaction between sodium oxide and trioxonitrate(V) acid $2Na^{+}O^{2-} + H^{+}NO_3^{-} = NaNO_3 + H_2O$  Hence the **equation** is as shown below $Na_2O + 2HNO_3 \longrightarrow 2NaNO_3 + H_2O$

CLOSURE 5 minutes	Teacher uses question and answer strategy to review the lesson and to find out whether students understood what was taught and whether the lesson objectives were achieved after which assignment was given to the students.	Students listen to the questions and answer them accordingly.	

REFERENCE:

Ameyibor, K. & Wiredu, M.B. (1991). *Chemistry for senior secondary schools.* Accra: Unimax Macmillan.

LESSON FOUR

1ST ITERATION

Topic: Writing of Chemical Formulae and Chemical Equations using the PCK Material

Duration: 80 minutes

Relevant Previous Knowledge: In the previous lesson, students were taught the ionic formulae of various metal ions, anions and radicals. Students were also taught how to identify ions in ionic compounds and their combination.

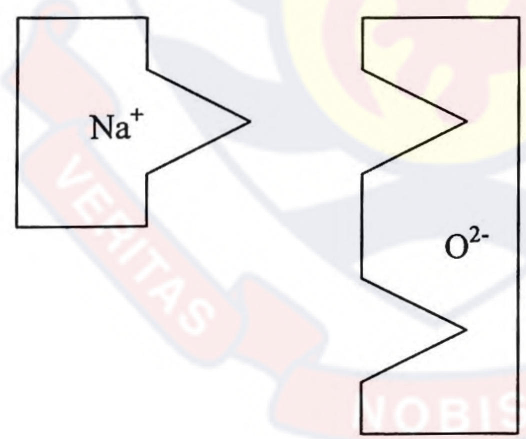
Specific Objectives

By the end of the lesson the student will be able to use the PCK material to:

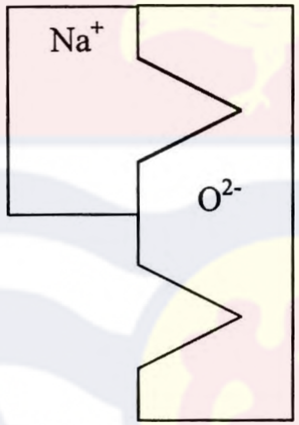
1. combine cations and anions to form neutral compounds
2. write chemical formulae of inorganic compounds
3. write chemical equations of combination, displacement and metathesis reactions

Teaching/Learning materials: PCK material

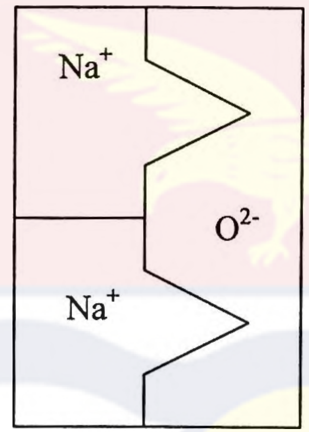
STAGE/ESTIMATED TIME	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
INTRODUCTION (5min)	Teacher uses question and answer technique to review students' previous knowledge as shown below: **QUESTION:** Write the formulae of the following ions: 7. aluminium ion 8. barium ion 9. chromium (III) ion 10. zinc ion 11. tetraoxophosphate (V) ion 12. trioxocarbonate (IV) ion	Students pay attention and answer the questions as follows: Al^{3+} Ba^{2+} Cr^{3+} Zn^{2+} PO_4^{3-} CO_3^{2-}	

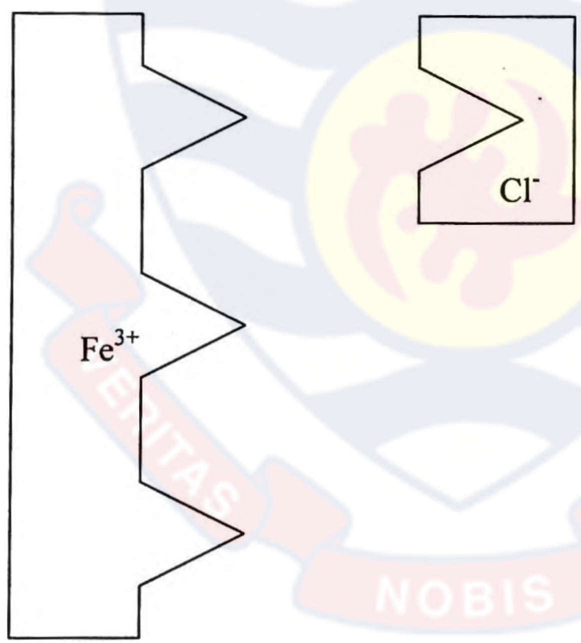
CONTENT DEVELOPMENT **STEP 1** **Combination of Ions to form Neutral Ionic Compounds and Writing of Chemical Formulae using PCK material** 30 minutes	Teacher uses demonstration method together with question and answer strategy to demonstrate to students how the PCK material is used to combine the ions they have identified to form neutral ionic compounds. **sodium oxide** Na^{+} and O^{2-} Valency = 1 valency = 2 	Students pay attention, listen and see the demonstrations.	

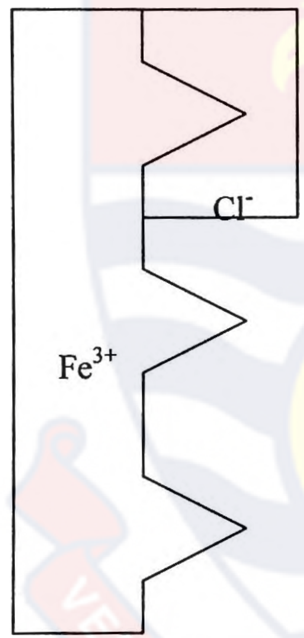
When the two ions bond, we will have the structure below:

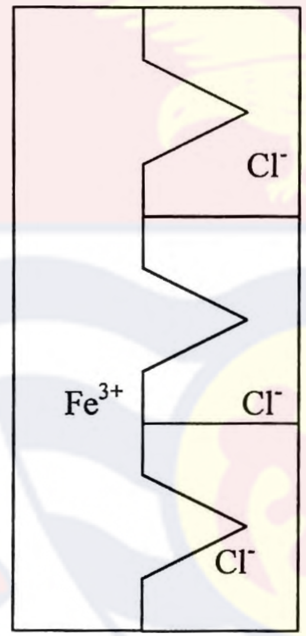


this means that one more Na atom is required to complete the structure as shown below:

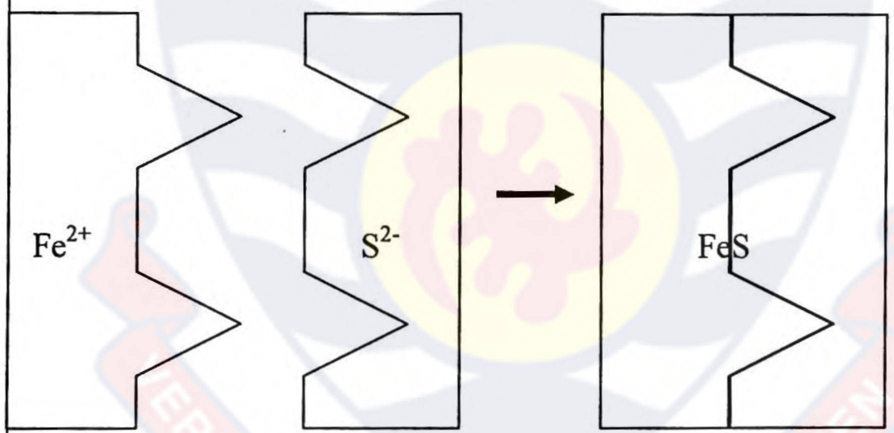
	 		
	Teacher asks students the following questions:	2	
	1. How many Na^+ did we use?	1	
	2. How many O^{2-} did we use?		
	2 atoms of Na + 1 atom O		
	Hence		
	the formula of sodium oxide is **Na_2O**		

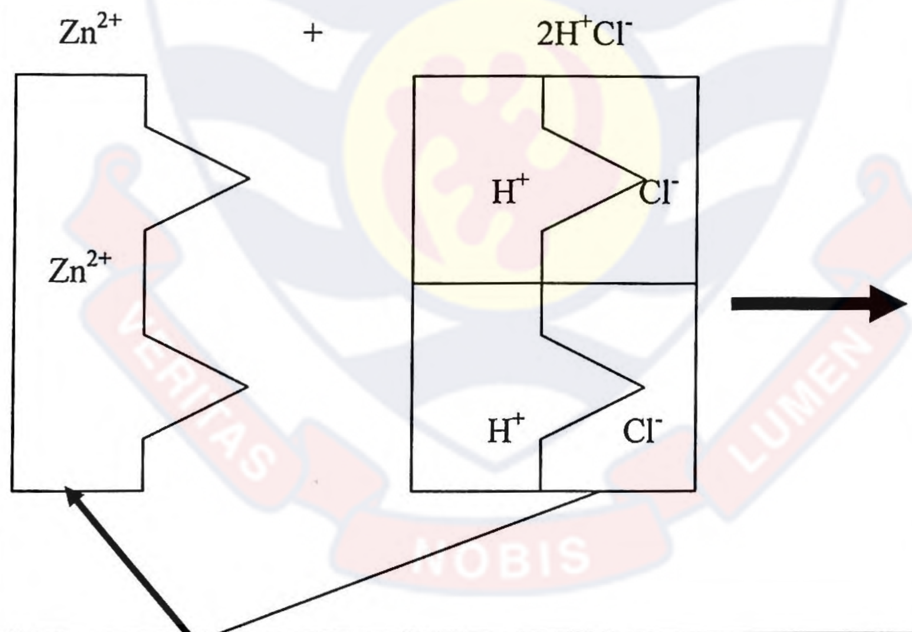
	Example 2 Teacher continues the demonstration with another example: **Iron (III) chloride** Fe^{3+} and Cl^- Valency = 3 Valency = 1 		

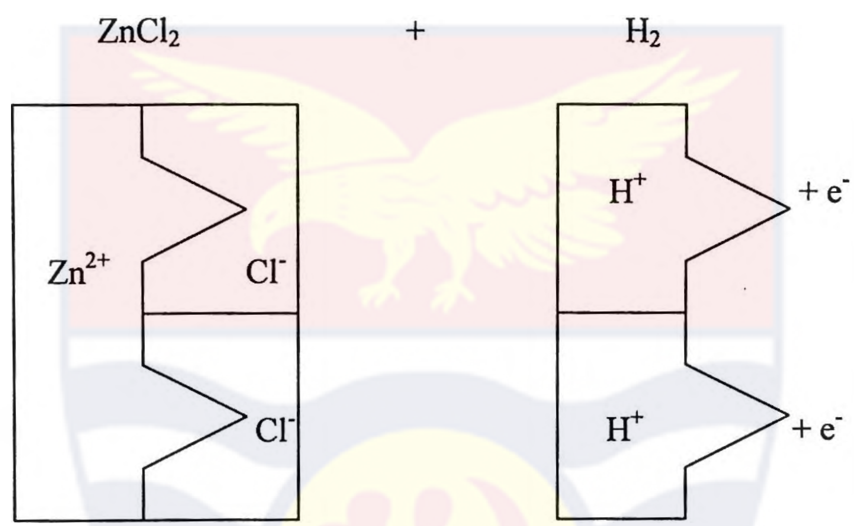
	When the above ions bond, the structure below is obtained:  <u>Question</u> How many Cl^- are needed to complete the structure?	2	

	Then the complete structure is as shown below:		
			
	<u>Questions</u>		
	1. How many Fe^{3+} did we use?	1	
	2. How many Cl^- did we use?	3	

	That is **1 atom of Fe (III) + 3 atoms of Cl** Hence, the formula of of Iron(III) chloride is **$FeCl_3$** Teacher then give students the PCK materials and asks them to use the materials to write the formulae of : (a) Potassium sulphide. (b) Copper (II) oxide (c) Aluminium chloride Teacher then go round and supervise the students as they carry out their task.	Students take the PCK materials and go through the same procedure to write the formulae of the compounds	
CONTENT DEVELOPMENT STEP 2	Teacher uses demonstration method to help students understand how equations of combination, displacement and metathesis reactions are written using the PCK material.	Students pay attention and observe the demonstration.	

Writing equations of Combination, Displacement and Metathesis reactions using PCK material 40 minutes	**Combination Reaction:** Example is **Reaction between iron (II) ion and sulphide ion to form iron(II) sulphide**  Hence the equation is $Fe^{2+} + S^{2-} \longrightarrow FeS$		

	Displacement Reaction **a. An active metal + an acid** Example is: 1. Reaction between Zinc metal and hydrochloric acid to form zinc chloride and hydrogen gas 		

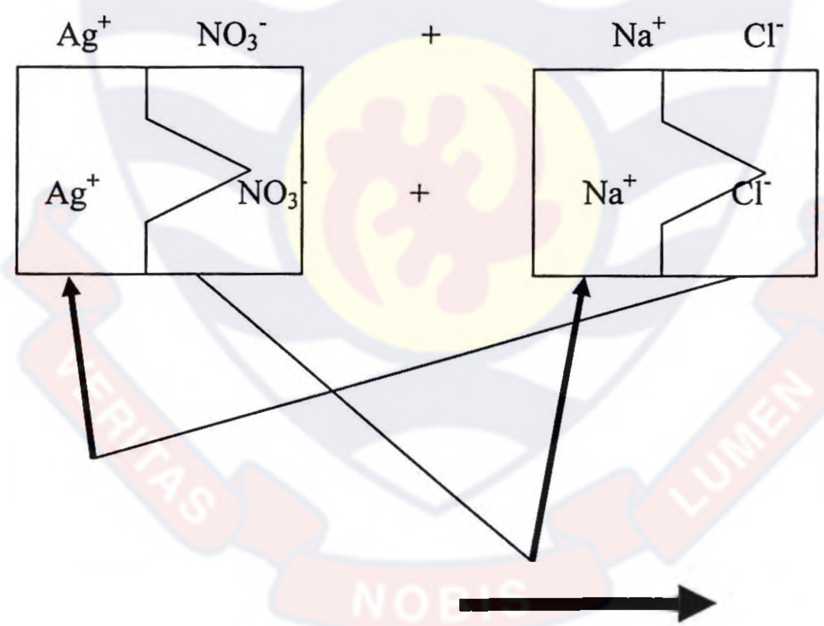
	 Hence the equation is $Zn + 2HCl \longrightarrow ZnCl_2 + H_2$		

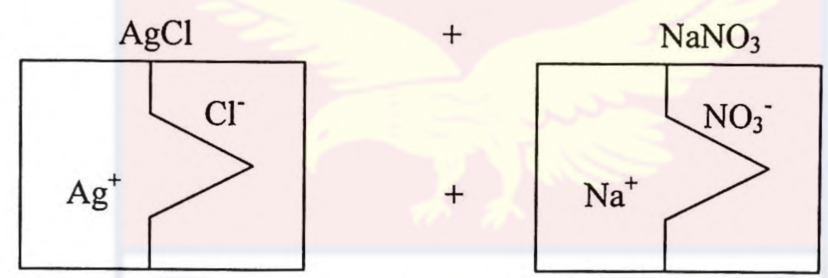
Metathesis or Double Displacement Reactions

a. Precipitation Reactions

Example is:

Reaction between silver trioxonitrate (V) and sodium chloride to form silver chloride and sodium trioxonitrate (V).



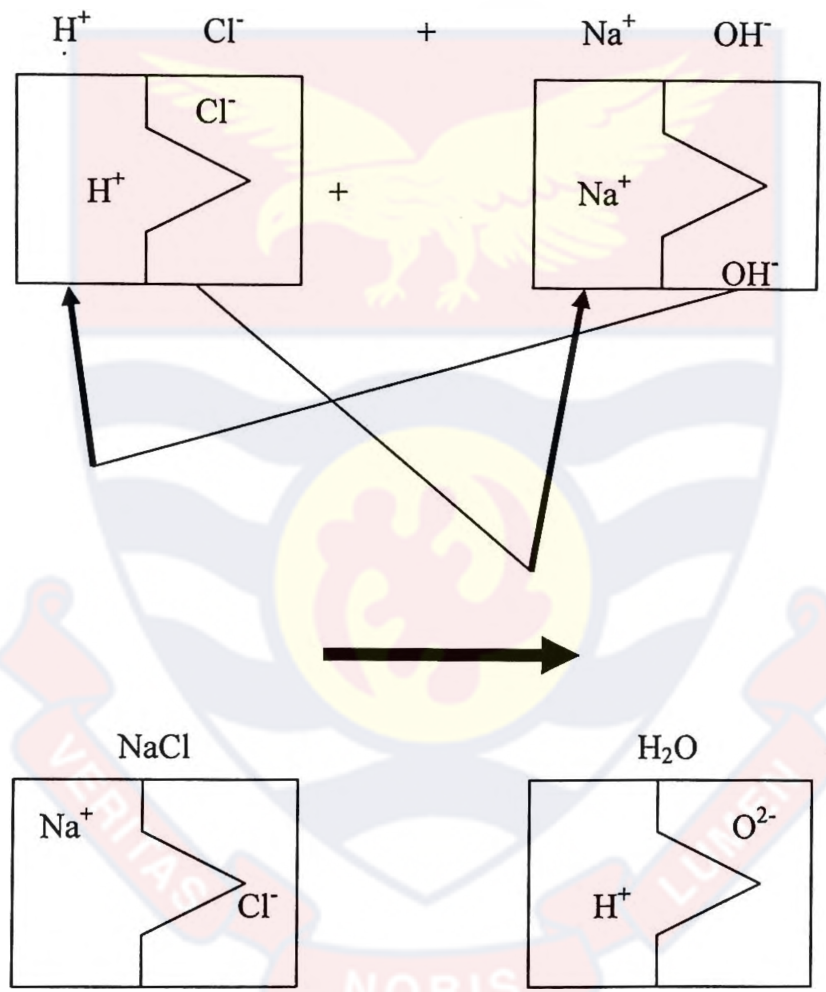


Hence the equation is

$$AgNO_3 + NaCl \longrightarrow AgCl\downarrow + NaNO_3$$

b. Neutralization Reactions (sometimes called acid-base reactions)

A neutralization reaction occurs between an acidic compound and a basic compound to form salt and water. Example is the reaction between hydrochloric acid and sodium hydroxide to form sodium chloride and water.

	 H+ Cl- + Na+ OH- Cl- H+ + Na+ OH- NaCl H2O Na+ Cl- O2- H+		

	Hence the equation is $HCl + NaOH \longrightarrow NaCl + H_2O$ Another example is the reaction between tetraoxosulphate (VI) acid and magnesium hydroxide to form magnesium tetraoxosulphate(VI) and water. Also in reactions between metal oxides and acids, the procedure is applied in writing the equation. Example is the reaction between calcium oxide and hydrochloric acid to form calcium chloride and water.		

	Teacher now gives the following tasks to students. Teacher goes round to supervise students as they carry out the task. **Task** Using the PCK material provided, write the chemical equations of the following reactions: (a) sodium ion with fluoride ion (b) magnesium with tetraoxosulphate (VI) acid (c) barium chloride with potassium tetraoxosulphate (VI)	Students take the PCK materials and go through the same procedure to write the chemical equations	

CLOSURE 5 mins	Teacher uses question and answer strategy to review the lesson and to find out whether students understood what was taught and whether the lesson objectives were achieved after which assignment was given to the students.		

REFERENCE:

Ameyibor, K. & Wiredu, M.B. (1991). *Chemistry for senior secondary schools.* Accra: Unimax Macmillan.

LESSON FIVE

2^{ND} ITERATION

Topic: Writing of Chemical Formulae and Chemical Equations using the PCK Material

Duration: 40 minutes

Relevant Previous Knowledge: In the previous lesson, students were taught how to write chemical formulae of inorganic compounds and chemical equations of some inorganic reactions using the PCK material.

Specific Objectives

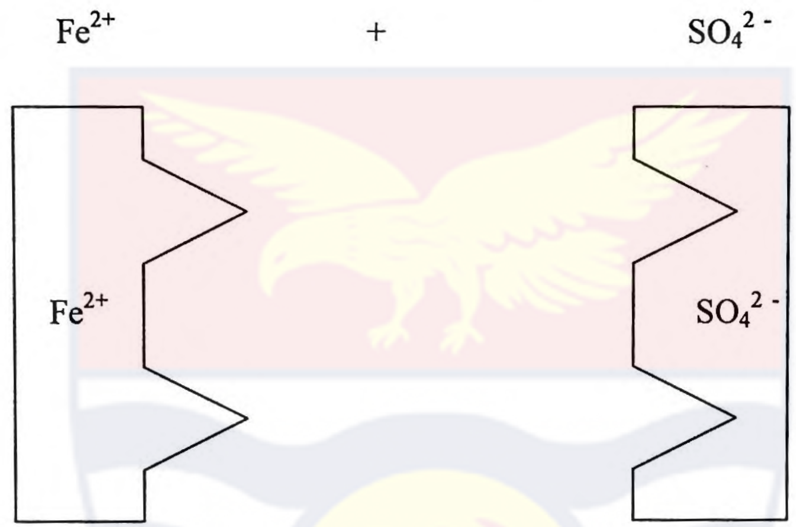
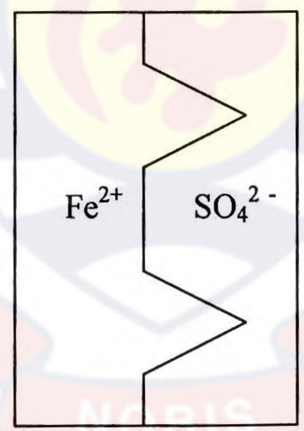
By the end of the lesson the student will be able to use the PCK material to:

1. write chemical formulae of inorganic compounds
2. write chemical equations of combination, displacement and metathesis reactions

Teaching/Learning materials: PCK material, charts of the periodic table of elements.

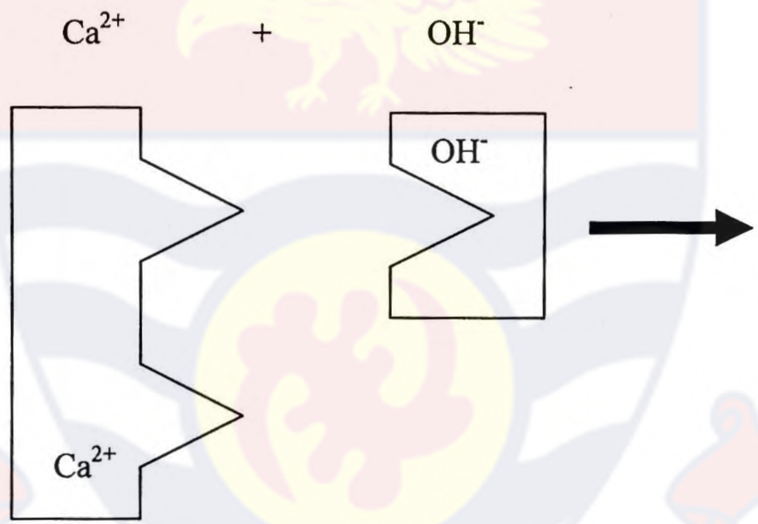
STAGE/ESTIMATED TIME	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
INTRODUCTION (5mins)	Teacher uses question and answer technique to review students' previous knowledge as shown below: **QUESTION:** Write the chemical formulae of the following compounds: 1. Lithium trioxocarbonate (IV) 2. Ammonium sulphide 3. Aluminium oxide	Students pay attention and answer the questions as follows: Li_2CO_3 $(NH_4)_2S$ Al_2O_3	

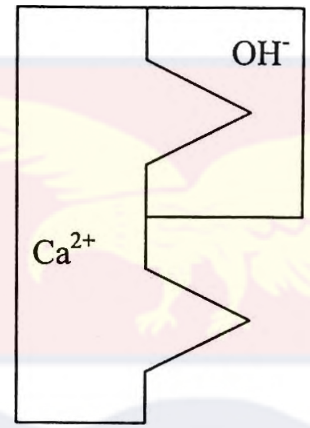
CONTENT DEVELOPMENT **STEP 1** **Writing of Chemical Formulae using PCK material** 15 minutes	Teacher uses demonstration method together with question and answer strategy to demonstrate to students how the PCK material is used to write chemical formulae of different compounds. Example **Iron (II) tetraoxosulphate(VI)** Fe^{2+} + SO_4^{2-} Valency = 2 Valency = 2	Students pay attention, listen and observe the demonstrations.	

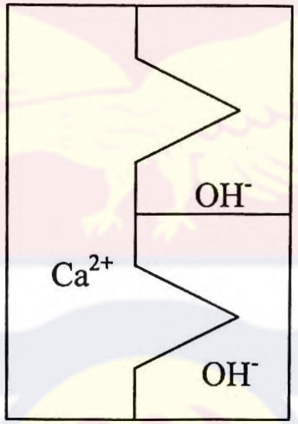
	 When the two ions bond together, we have the structure below 		

	At this stage, teacher asks students the following questions to elicit their understanding: 1. How many Fe^{2+} ions did we use to complete the structure? 2. How many SO_4^{2-} ions did we use to complete the structure? 3. Hence what will be the chemical formula of : Iron (II) tetraoxosulphate (VI)	 1 1 **$FeSO_4$**	

	Teacher now gives the following tasks to students. Teacher goes round to supervise students as they carry out the task. **Task** Using the PCK material provided, write the chemical formulae of the following compounds: (a) copper (I) oxide (b) aluminium bromide (c) sodium trioxocarbonate (IV)	Students take the PCK materials and go through the same procedure to write the formulae of the compounds	

CONTENT DEVELOPMENT **STEP 2** **Writing of Chemical Equations of Combination, Displacement and Metathesis Reactions using PCK material** 15 minutes	**Combination Reaction** Example Reaction between calcium ion and hydroxide ion to form calcium hydroxide 		

	 Teacher asks the following questions: 1. How many Ca^{2+} ions are needed to complete the structure? 2. How many OH^- ions are needed to complete the structure?	1 2	

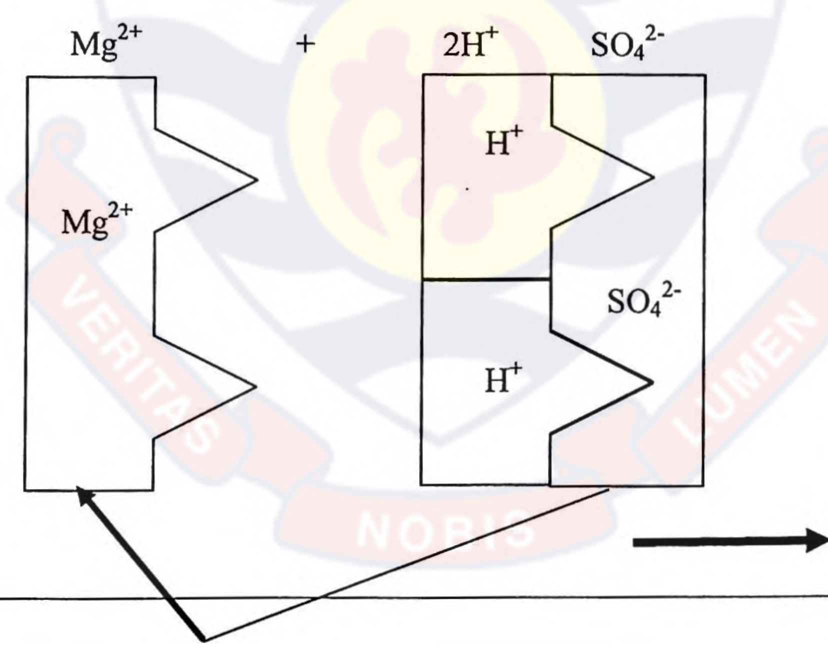
	Hence the completed structure is as shown below:  Therefore write the ionic equation for the formation of calcium hydroxide.	$Ca^{2+} + 2OH^- \longrightarrow Ca(OH)_2$	

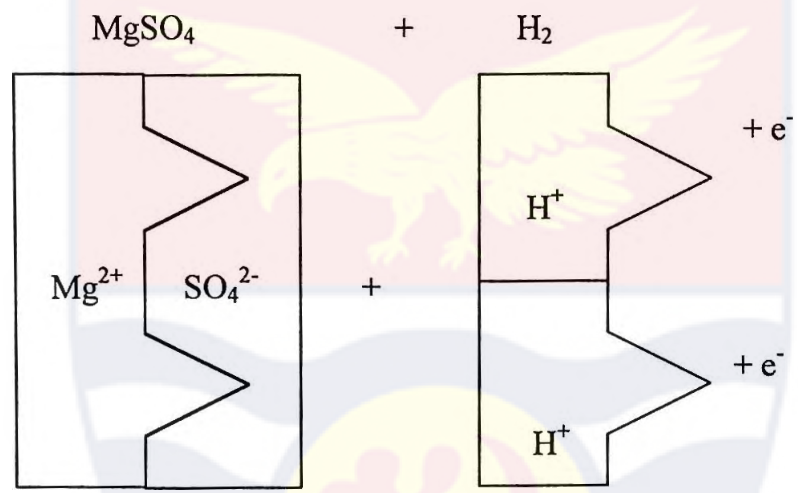
Displacement Reaction

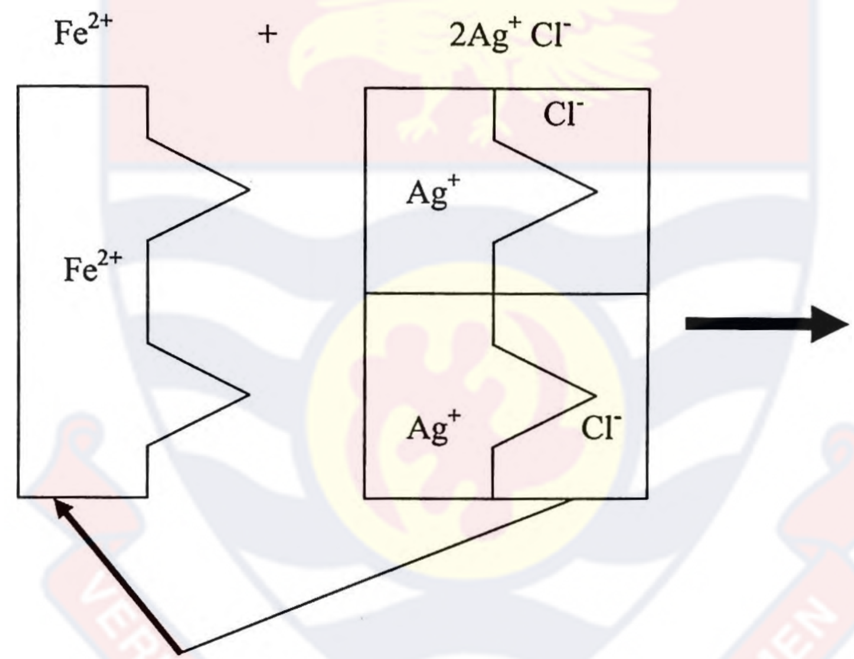
a. An active metal + an acid

Example

Reaction between magnesium metal and tetraoxosulphate (VI) acid



	 Teacher now asks students to write the chemical equation of the reaction	$Mg + H_2SO_4 \longrightarrow MgSO_4 + H_2$	

	b. A metal + a salt An example is: Reaction between Iron (II) metal and silver chloride to form Iron (II) chloride and silver metal 		

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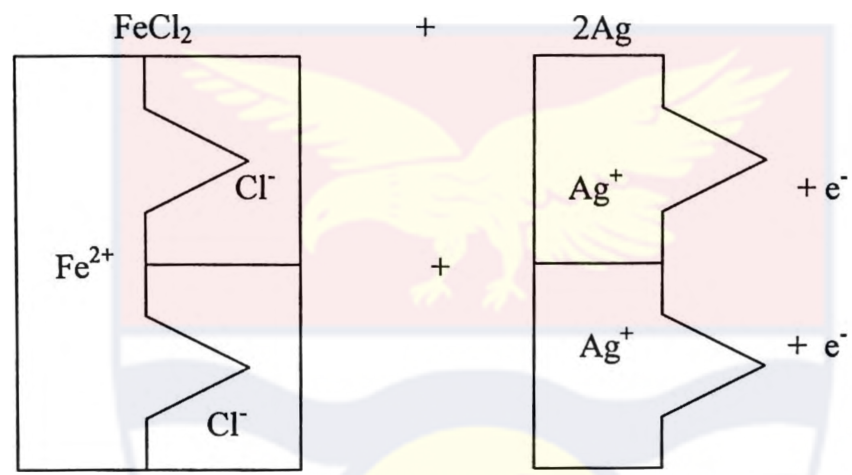

At this stage teacher asks students to write the chemical equation of the above reaction
</td>
<td>Fe^{2+} + 2AgCl ⟶ $FeCl_2$ + 2Ag</td>
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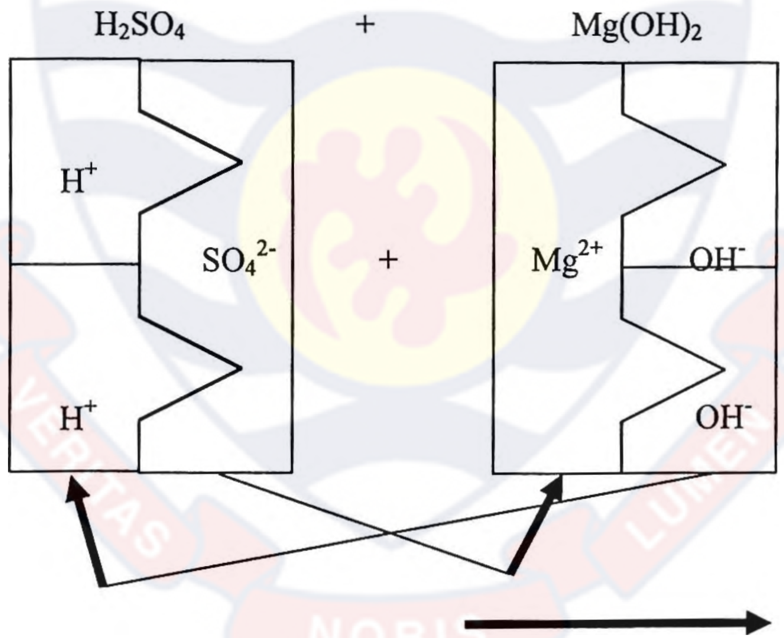
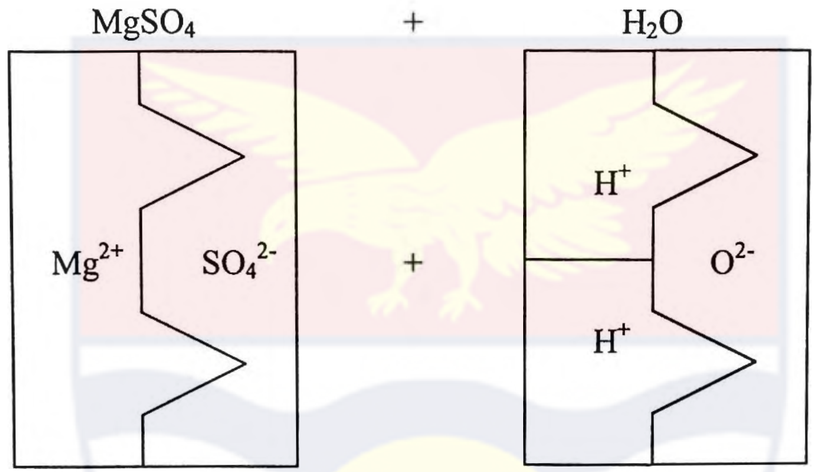
	Metathesis or Double Displacement Reactions Example is the neutralization reaction between tetraoxosulphate (VI) acid and magnesium hydroxide to form magnesium tetraoxosulphate sulphate (VI) and water. 		

	 Teacher now asks students to write the chemical equation of the metathesis reaction above.	$H_2SO_4 + Mg(OH)_2 \longrightarrow MgSO_4 + H_2O$	

	Teacher now gives the following tasks to students. Teacher goes round to supervise students as they carry out the task. **Task** Using the PCK material provided, write the chemical equations of the following reactions between: (a) aluminium ion and nitride ion (b) aluminium metal and tetraoxophosphate (V) acid (c) barium chloride and potassium sulphate	Students take the PCK materials and go through the same procedure to write the chemical equations.	
Closure 5 mins	Teacher uses question and answer strategy to review the lesson and to find out whether students understood what was taught and whether the lesson objectives were achieved after which assignment was given to the students.		

LESSON SIX

3RD ITERATION

Topic: Writing of Chemical Formulae and Chemical Equations using the PCK Material

Duration: 40 minutes

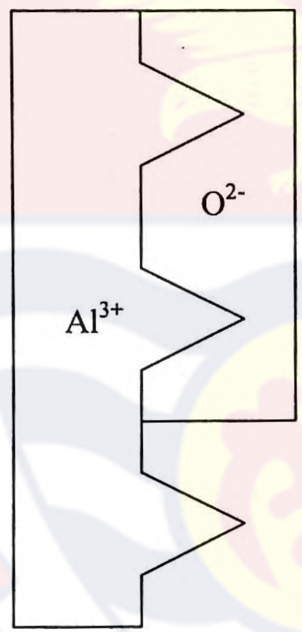
Relevant Previous Knowledge: In the previous lesson, students were taught how to write chemical formulae of inorganic compounds and chemical equations of some inorganic reactions using the PCK material.

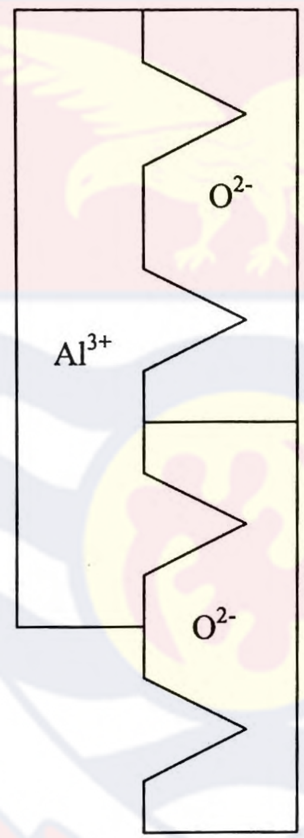
Specific Objectives

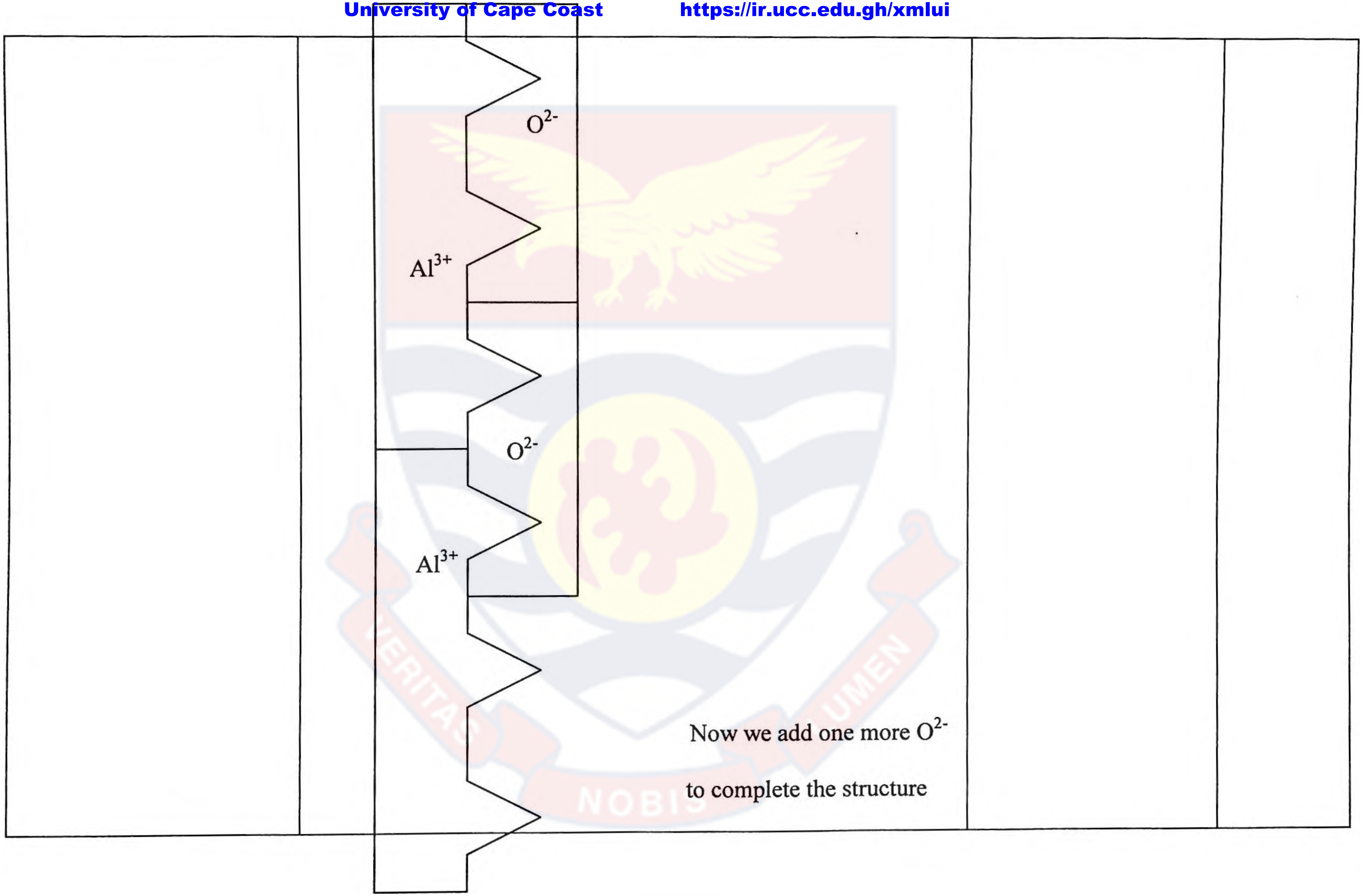
By the end of the lesson the student will be able to use the PCK material to:

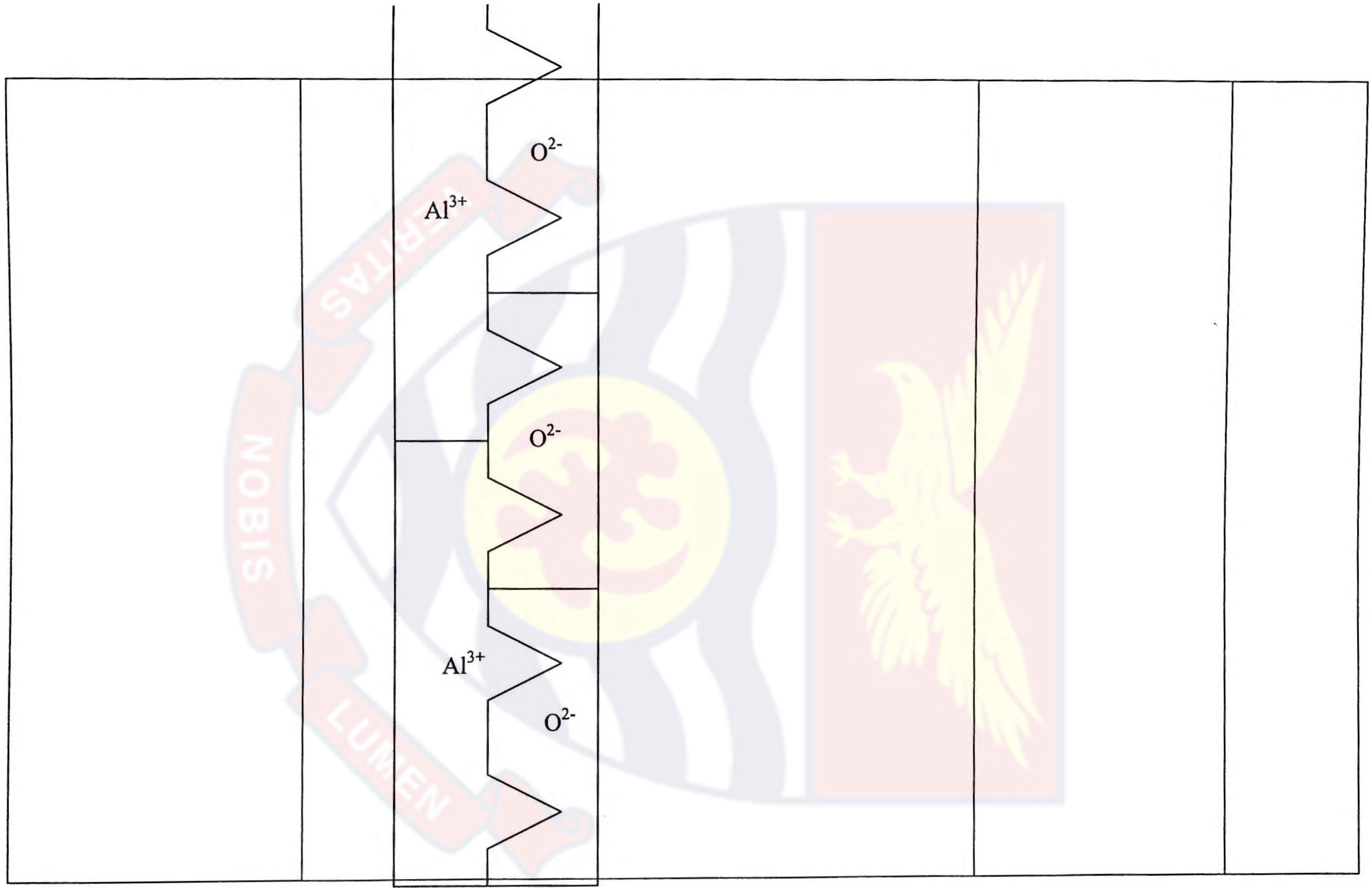
1. write chemical formulae of inorganic compounds
2. write chemical equations of combination, displacement and metathesis reactions

Teaching/Learning materials: PCK material, charts showing rules for assigning oxidation numbers.

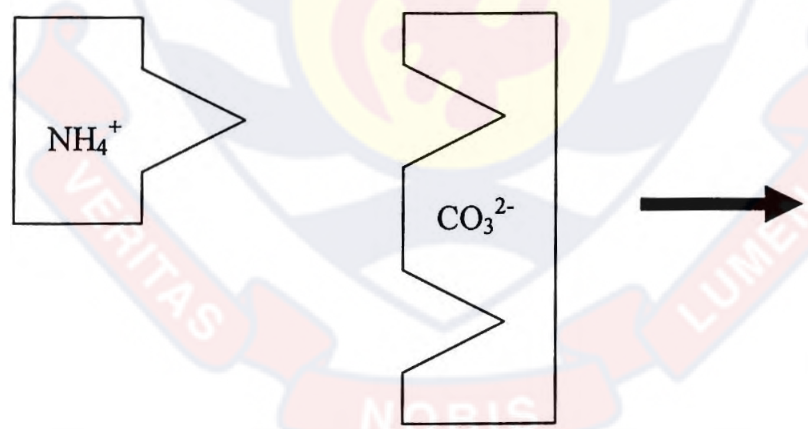
	When the two ions bond, we will have the structure below:  Let us add a second O^{2-} to the structure above		

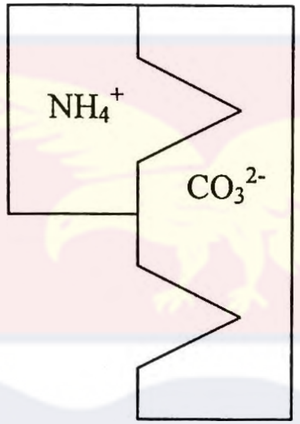
	 At this stage, we add a second Al^{3+} to the structure above		

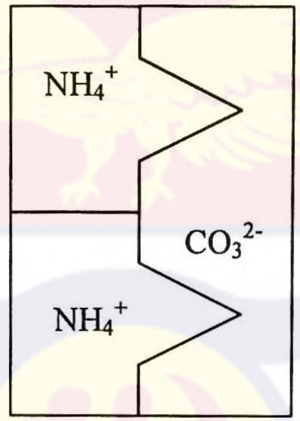

O^{2-}
Al^{3+}
O^{2-}
Al^{3+}
Now we add one more O^{2-}
to complete the structure


O^{2-}
Al^{3+}
O^{2-}
Al^{3+}
O^{2-}

	Teacher asks students the following questions to find out whether they understood the demonstration. 1. How many Al^{3+} did we use to complete the structure? 2. How many O^{2-} did we use to complete the structure? 3. Hence write the chemical formula of aluminium oxide	 2 3 Al_2O_3	
	TASK Teacher then give students the PCK materials and asks them to use the materials to write the formulae of : (a) Aluminium nitride. (b) Sodium tetraoxochlorate (VII) (c) Zinc trioxocarbonate (IV) Teacher then go round and supervise the students as they carry out their task.	Students take the PCK materials and go through the same procedure to write the formulae of the compounds	

CONTENT DEVELOPMENT **STEP 2** **Writing equations of Combination, Displacement and Metathesis reactions using PCK material** 15 minutes	Teacher uses demonstration method to help students understand how equations of combination, displacement and metathesis reactions are written using the PCK materials. **Combination Reaction** Example Reaction between ammonium ion and trioxocarbonate (IV) ion to form ammonium trioxocarbonate (IV) NH_4^+ + CO_3^{2-} 	Students pay attention and observe the demonstration.	

			
	1. How many NH_4^+ ions do we need to complete the structure?	2	
	2. How many CO_3^{2-} ions do we need to complete the structure?	1	

	The complete structure is as shown below  Hence write the ionic equation for the formation of ammonium trioxocarbonate (IV)	$2\ NH_4^+ + CO_3^{2-} \longrightarrow (NH_4)_2\ CO_3$	

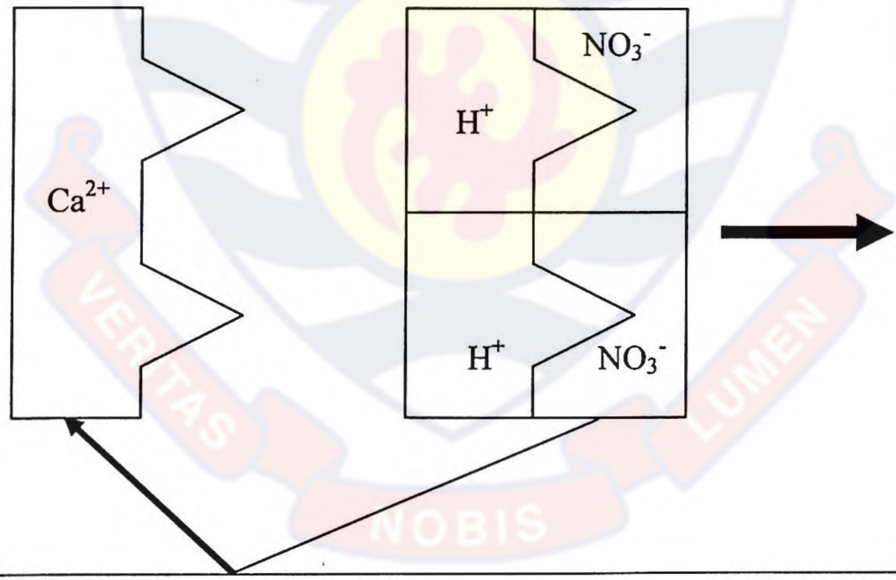
Displacement Reaction

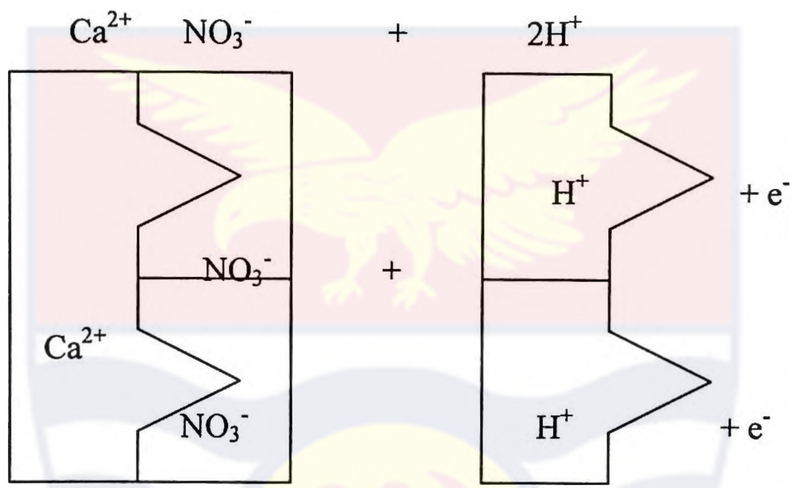
a. An active metal + an acid

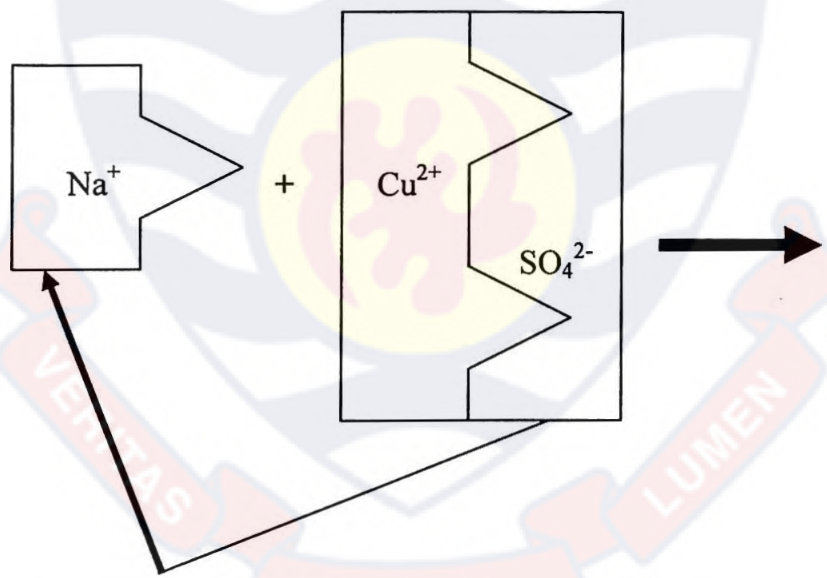
Examples is:

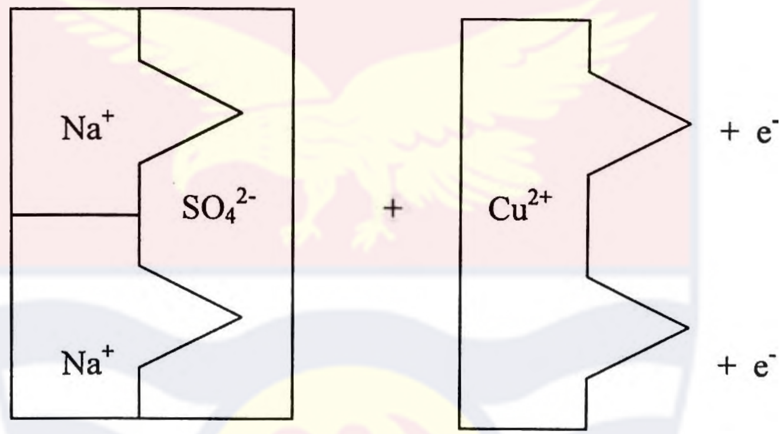
1. Reaction between Calcium metal and trioxonitrate (V) acid to form Calcium trioxonitrate (V) and hydrogen gas

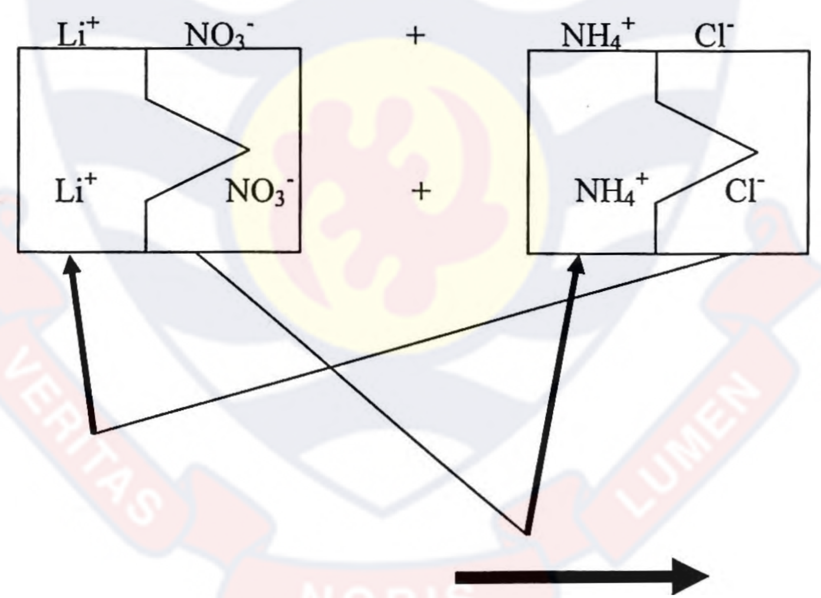
Ca^{2+} + $2H^{+}NO_3^{-}$

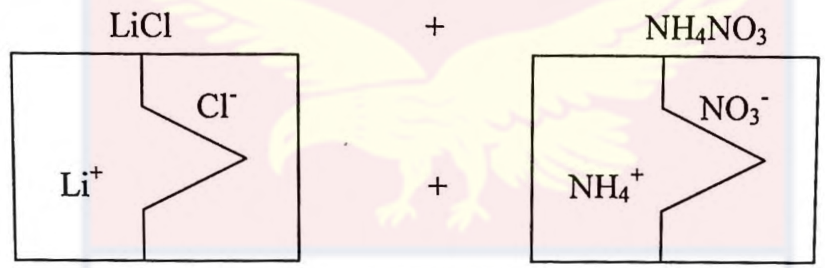


	 Teacher now asks students to write the equation of reaction between calcium metal and trioxonitrate (V) acid	Students write the equation as $Ca + HNO_3 \longrightarrow$ $Ca(NO_3)_2$	

	b. A metal + a salt An example is: Reaction between sodium metal and copper (II) tetraoxosulphate (VI) to form sodium tetraoxosulphate (VI) and copper (II) metal Na^+ + Cu^{2+} SO_4^{2-} 		

	 		
	Teacher asks students the following questions		
	1. How many Na^+ did we use to complete the structure?	2	
	2, Hence, write the chemical equation of the above reaction	$Na + CuSO_4 \rightarrow$ $Na_2SO_4 + Cu$	

	Metathesis or Double Displacement Reactions Example is the reaction between lithium trioxonitrate (V) and ammonium chloride to form lithium chloride and ammonium trioxonitrate (V) 		

	 Teacher now asks students to write the chemical equation of the above reaction Teacher now gives the following tasks to students. Teacher goes round to supervise students.	$LiNO_3 + NH_4Cl \longrightarrow LiCl + NH_4NO_3$	

	Task Using the PCK materials provided, write the chemical equations of the following reactions: (a) ammonium ion with tetraoxochlorate (VII) ion (b) silver metal with tetraoxosulphate (VI) acid (c) sodium oxide with trioxonitrate (V) acid	Students take the PCK materials and go through the same procedure to write the chemical equations	

CLOSURE 5 mins	Teacher uses question and answer strategy to review the lesson and to find out whether students understood what was taught and whether the lesson objectives were achieved after which assignment was given to the students.		

REFERENCE:

Ameyibor, K., & Wiredu, M.B. (1991). *Chemistry for senior secondary schools.* Accra: Unimax Macmillan.

CHAPTER FOUR

RESULTS AND DISCUSSION

In this chapter, the results from the study into development of teaching and learning material for chemical formulae and chemical equations are presented and discussed in relation to four research questions and twelve hypotheses. Cross-sectional survey and one group pre-test-post-test experimental design were used in which quantitative and qualitative methods were employed. The sample consisted of 98 SHS 1 science students with 38 boys and 60 girls, 99 SHS 2 science students comprising of 84 boys and 15 girls and 20 SHS chemistry teachers selected from the population. The mean age of the SHS 1 students was 16.9 with standard deviation of 1.4 and the mean age of the SHS 2 students was also 16.9 with standard deviation of 1.2.

The two science classes were first pre-tested to determine their initial difficulties and conceptions after which they were taken through series of iterations and followed through to see how their conceptions of the two topics changed as they went through the iterations to develop the teaching and learning material. The study also sought the views of SHS chemistry teachers about issues concerning the teaching and learning of chemical formulae and chemical equations of inorganic compounds and highlights of the teachers' views were factored into the development of the teaching and learning material.

The qualitative and statistical analyses of the data from of the study are presented in eight sections:

(a) Views of SHS chemistry teachers on issues concerning the teaching and learning of chemical formulae and chemical equations at the SHS level.

(b) Initial difficulties of SHS 1A and SHS 2A science students on the writing of chemical formulae and chemical equations.

(c) Performance of SHS 1A and SHS 2A science students in the various post-tests during development of the teaching and learning material.

(d) Performance of the validation SHS 1 science students in the pre-test and post-test during validation of the teaching and learning material already developed.

(e) Determination of the difference in the degree of changes in conceptions of SHS 1A and SHS 2A science students between their pre-test and post-test 3 on writing of chemical formulae and chemical equations during development of the teaching and learning material in this study.

(f) Determination of the difference in the degree of changes in conceptions of validation SHS 1 science students between their pre-test and post-test on writing of chemical formulae and chemical equations during validation of the teaching and learning material in this study.

(g) Determination of the differences between the pre-test and the post-test 3 results in the writing of chemical formulae and chemical equations of SHS 1A and SHS 2A science students who were taught with the teaching and learning material developed in this study.

(h) Determination of the differences between the pre-test and the post-test results of chemical formulae and chemical equations of the validation

SHS 1 science students during validation of the teaching and learning material.

Views of SHS Chemistry Teachers About Issues Concerning the Teaching and Learning of Chemical Formulae and Chemical Equations at the SHS level

Research question 1 sought to find the views of SHS chemistry teachers about issues concerning the teaching and learning of chemical formulae and chemical equations of inorganic compounds (see Appendices O and P for details). An open ended questionnaire was administered to 20 SHS chemistry teachers selected randomly from all the Senior High Schools that offer science programme in the population. The information requested from the chemistry teachers about writing of chemical formulae and chemical equations are shown in Appendices O and P.

The first item on the questionnaire requested from the teachers what they considered as ideas central to writing of chemical formulae of inorganic compounds. According to the teachers' responses, the ideas that are central to writing chemical formulae of inorganic compounds were: first of all, introduction of the students to chemical symbols of elements and this to them, must be followed immediately by knowledge of atomic numbers of the elements. After this, students must know the group and periods of the elements as well as their valencies or oxidation numbers. This should be followed by electronic configuration of the elements after which the concept of electronegativity and electropositivity of elements could be introduced. Students at this stage could be introduced to the formulae of radicals or polyatomic ions and their valencies or oxidation numbers. Then, the concept of reactivity of elements and radicals and how they interchange valencies and written as subscripts could be taught. Finally, students could be helped to distinguish between empirical, molecular and structural formulae.

The second item on the questionnaire requested from the teachers the difficulties/limitations connected with teaching chemical formulae of inorganic compounds. From the responses gathered from the teachers, the difficulties/limitations connected with teaching chemical formulae of inorganic compounds were: students inability to state the chemical symbols of the various elements or atoms due to poor mastery of chemical symbols from the basic level, students sluggish mastery of the rules for assigning oxidation numbers, students inability to remember the valencies of the various elements, students difficulty understanding why there should be brackets in chemical formulae involving radicals or oxoanions. According to the teachers, students sometimes get confused when it comes to a metallic atom combining with a radical and their confusion is where to write bracket and the valency of the metal outside the bracket. Taking $Ca(OH)_2$ for instance, a lot of students will prefer writing it as $CaOH_2$. According to the teachers, finding scenarios or practical ways to help students understand the topic is a problem. Furthermore, non availability of concrete teaching and learning materials or non availability of models or software for e-learning of chemical formulae makes the topic too abstract to students. Poor presentation of the topic in textbooks or lack of quality books on the topic is also a problem.

There is also difficulty in getting students to follow the laid down principles in determining empirical formulae when substances or compounds are quoted in either percentage or mass compositions. Another area of difficulty in teaching chemical formulae is the issues about how to get students understand the concept of variable oxidation states exhibited by some elements in their compounds. According to the teachers, there is difficulty in making the lesson practical and hence difficulty in relating the lesson to everyday life. Also, there is difficulty in making the lesson student oriented. There are inadequate charts of the periodic table to make the electronic arrangement of atoms more practical to students.

When the teachers were asked in item 3 to state the difficulties/limitations students have with learning chemical formulae of inorganic compounds, the teachers provided the following information: weak foundation from JHS makes learning of the topic difficult to the students. Students' inability to translate names of species especially radicals into formulae and difficulty in learning, remembering and applying the rules for naming inorganic compounds is problem to many students. According to the teachers, another interesting problem on the part of the students is their difficulty with the use of capital letters in writing chemical symbols. Also students have difficulty knowing when to put a particular part of a chemical formula into bracket example $Mg(OH)_2$. Understanding the oxidation states of the various elements in chemical formulae is a problem to many students. Additionally, students have problems in: assigning the elements to their groups and periods, assigning oxidation numbers to elements with variable oxidation states and difficulty writing the correct ionic form of the elements.

When the teachers were asked to indicate the teaching procedures they use to help their students understand writing of chemical formulae of inorganic compounds in item 4, the teachers said: they help students to assign and easily remember the rules for assigning oxidation numbers and solve more examples on oxidation numbers with students, they help students to identify and distinguish between ions, acids, bases, salts and binary compounds, thorough revision of chemical or atomic symbols since it is poorly taught at the JHS level, demonstration with improvised models on the electronic arrangement in the atom with regard to configuration and stability, introduction of students to ions formation (cations and anions), a brief introduction into periodic chemistry, discussion of valency, extensive discussion of the elements of the periodic table and their groups using a chart of the periodic table, thorough revision of what students did about the topic at the JHS, thorough discussion of the rules for assigning oxidation numbers and valencies and how valencies are exchanged between two elements, an element and a radical and two radicals. Responses from the teachers also revealed that they use following methods of teaching to help their students: group work, problem-solving method, discussion method, role play and demonstration as well as strategies as use of mnemonics to help students memorize chemical symbols, dramatization. Solving of more questions on the topic, giving students a lot of examples and supervising to ensure that they do it and asking students to do research in the form of assignment where students are asked to go online and look for the chemical formulae of certain compounds.

Concerning how SHS chemistry teachers ascertain students' understanding or confusion around chemical formulae the following responses were prominent: calling students at random to answer questions in class, going round during classes hours to inspect examples given, looking at facial expression of students, from questions asked by students in class, from the level of students concentration in class and through feedback from class tests, class exercises, assignments and project works or group works.

According to the SHS chemistry teachers, the points that are central to writing of chemical formulae are all inclusive in the points central to writing of chemical equations of inorganic reactions. The following were the additional points from the teachers: knowledge of the laws of chemical combination, knowledge of mole concept, knowledge of stoichiometry, correct IUPAC names, symbols and formulae of substances involved in a reaction, symbols showing the physical state of each substance involved in a reaction, students ability to predict the correct products of chemical equations, knowledge of word equation, knowledge of how to exchange valencies between elements and radicals at both the reactant and product sides and knowledge of how to balance chemical equations using numbers only in front of the species in the equation and not behind them.

When it came to the difficulties/limitations connected with teaching chemical equations, the teachers said the following in addition to the difficulties/limitations connected with teaching chemical formulae: getting students to picture what possibly happens in reactions is a problem, students poor knowledge in mole concept makes the topic difficult to teach, students' inability to write the correct chemical symbols for some elements and chemical formulae for most compounds makes the topic difficult to teach. Also inadequate teaching and learning materials for chemical equations is a problem, firm foundation for chemical equations takes a lot of time, difficulty in helping students determine the products of a reaction, students see the topic as abstract and this poses a problem to their understanding of the topic. Also, the concept of charge neutrality of products formed in reactions is a problem to students and students find it difficult to tell the correct state of a product formed in a reaction.

For the difficulties/limitations connected with learning chemical equations, the teachers said the following in addition to the difficulties/limitations connected with learning chemical formulae: students have difficulty in writing the products formed when inorganic substances react, students show lack of understanding of monoatomic, diatomic and triatomic species, students have difficulties in handling mathematical data in relation to chemical formulae and chemical equations, students have difficulty in determining whether a reaction is reversible or irreversible. Also, students are unable to balance the equations they write especially ionic equations because in their attempt to balance the equations they write, they end up changing the formulae of the compounds involved in the reaction, students have difficulty predicting the correct products of reactions, students show lack of exposure to many chemical formulae and their IUPAC names, students have difficulty knowing the type of reaction they are dealing with, difficulty knowing the state of a products formed in a reaction and difficulty writing the correct chemical formulae of reactants and products in a reaction.

Concerning the teaching procedures teachers use in helping their students understand chemical equations, the teachers stated the following procedures in addition to the procedures they use in teaching formulae writing: discussion on the formation of products of reactions using word reactions first before representing chemical reactions with symbols, discussion of concepts associated with the states of both reactants and products before and after a chemical reaction, discussion of the various types of chemical reactions with students, discussion with students on the type of product to expect depending on the type of reaction, discussion with students on how to determine the state of a product formed in a reaction and demonstrate to students how to balance chemical equations.

Then finally, regarding how teachers ascertain students' understanding or confusion around chemical equations, the teachers included all that they said under chemical formulae in addition to: comments from Chef Examiners' Reports, through discussions at GAST conferences and through discussions with fellow chemistry teachers.

Initial Difficulties of SHS 1A & 2A Science Students Before Instruction with the Teaching and Learning Material.

Research question 2 sought to investigate the initial difficulties of SHS 1A and SHS 2A science students who were used to develop the teaching and learning material in this study. To achieve this, the students were pre-tested separately on writing of chemical formulae and chemical equations. The chemical formulae pre-test consisted of the IUPAC names of nine inorganic compounds and each compound had five sub-questions (a-e). Sub-question (a) requested the formula of the compound, (b) tasked the students to write the constituent ions in the compound, (c) demanded the subscripts of the constituent ions, (d) asked the students to explain the meaning of the subscripts in (c) and (e) requested the students to write the valency of each constituent ion in the compound. The performances of all SHS 1 and 2 students who took part in the pre-test are shown in Tables 18-22 but the performances of SHS 1A and SHS 2A in the chemical formulae pre-test are shown in Table 23 below.

Table 23-*Initial Performances of SHS 2A and SHS 1A Science Classes on Writing of Chemical Formulae in the Pre-Test*

	SHS 2A and SHS 1A Science Classes			
	2A (N = 36)		1A (N = 25)	
Questions	Mean	SD	Mean	SD
a. (1 – 9)	2.54	4.01	2.20	3.78
b. (1 – 9)	1.87	3.75	5.92	7.17
c. (1 – 9)	0.57	2.04	1.84	4.28
d. (1 – 9)	0.57	2.04	1.92	3.20
e. (1 – 9)	1.30	2.90	3.84	6.14

From Table 23, the general performance of the two classes in the chemical formulae pre-test was rather poor. This is because out of the total mark of 45, none of the two classes scored even one-fourth. Questions a. (1 – 9), b. (1 – 9), c. (1 – 9), d. (1 – 9) and e. (1 – 9) carried a total mark of 9 marks each however, none of the classes scored even 4.5 with c. (1 – 9), d. (1 – 9) producing the worst mean marks. This shows that students' knowledge of subscripts of constituent ions and what they mean is very poor.

For each compound, students wrote various wrong formulae and the details are shown in Appendices S-A1. Out of the 99 SHS 2 students who took part in the pre-test, 40.4% of them wrote the chemical formula of Iron (III) trixoxocarbonate (IV) as $FeCO_3$ and 12.1% wrote it as $Fe_2(CO_2)_3$ and out of 98 SHS 1 students who took part in the pre-test, 25.5% of them wrote the formula of the same compound as Fe_2CO_3 and 18.4% of them wrote it as $FeCO_3$. For the compound, Silver nitride, 30.3% SHS 2 students wrote it as AgN, 16.1% wrote it as $AgNO_3$ and 10.1% wrote it as Ag_2N. For the same compound, 32.7% SHS 1 students wrote it $Ag(NO_2)_2$, 22.4% wrote it as AgN and 16.3% of them wrote it as $AgNO_3$. With regard to the compound Iron (III) tetraoxosulphate (VI) 28.3% SHS 2 students wrote the formula as Fe_3SO_4 and 25.5% SHS 1 students also gave the same formula. The chemical formula of Ammonium trioxocarbonate (IV) was given by 40.4% SHS 2 students as NH_4CO_3. The same formula was also given by 31.6% SHS 1 students. Also, 35.4% SHS 2 students wrote the formula of Lithium trioxocarbonate_(IV) as $LiCO_3$_as against 21.4% SHS 1 students who gave the same formula for the compound. Concerning the compound, Aluminium tetraoxosulphate (VI), 25.3% SHS 2 students wrote the formula as Al_2SO_4 and 17.2% of them wrote it as $AlSO_4$. Also 15.3% SHS 1 students gave the formula as $AlSO_4$ and 12.2% wrote it AlH_2SO_4. For Copper (II) tetraoxophosphate (V), 40.4% SHS 2 students gave the formula as $CuPO_4$ and 28.6% SHS 1 students gave the same formula but additional 25.5% SHS 1 students also gave the formula as $CuSO_4$. Furthermore, 35.4% SHS 2 students gave the formula of Ammonium sulphide as NH_4S and 30.6% SHS 1 students also gave the same formula.

From the answers given by both SHS1 and SHS 2 science students in the pre-test on writing of chemical formulae, the following difficulties were identified:

(a) Students do not understand the meaning of Roman numerals in parenthesis of IUPAC names.

(b) Students have not grasped the correct formulae of ions of the elements and the situation is more serious with radicals. Some of the ions were even not familiar to the students. Examples were tetraoxophosphate (V) ion and the nitride ion.

(c) The concept of valency and the role it plays in the writing of chemical formulae is poorly understood by both SHS 1 and SHS 2 students. Examples, 54.8% of SHS 2 science students (see Appendix S) wrote the chemical formula of iron (III) trixoxocarbonate (IV) as $FeCO_3$. Sixty percent of SHS 2 students and 40.8% SHS 1 students (see Appendix V) wrote the chemical formula of ammonium trioxocarbonate (IV) as NH_4CO_3. Also, 41.2% SHS 2 students gave the formula of ammonium sulphide as NH_4S as against 34.5% SHS 1 students who gave the same formula.

(d) Students found it difficult to determine the constituent ions of ionic compounds let alone combining the ions to form a neutral compound.

(e) High percentage failure of both classes in sub-questions (c) and (d) is an indication that students have poor knowledge of subscripts of constituent ions and what those subscripts represent. Students' difficulty with subscripts of constituent ions was largely due to their inability to write the formulae of the constituent ions as shown in Table 24.

Table 24 - *Number and Percentages of all Students who took part in the Pre-test and could not write the Constituent ions of the Compounds.*

Compounds	SHS 1(N = 98)		SHS 2 (99)	
	No	(%)	No	(%)
Iron (III) trixoxocarbonate (IV)	50	(51.0%)	74	(74.7%)
Silver nitride	92	(93.9%)	88	(88.9%)
Iron (III) tetraoxosulphate (VI)	68	(69.4%)	77	(77.8%)
Ammonium trioxocarbonate (IV)	70	(71.4%)	78	(78.8%)
Lithium trioxocarbonate (IV)	93	(94.9%)	74	(74.7%)
Aluminium tetraoxosulphate (VI)	63	(64.3%)	75	(75.8%)
Copper (II) tetraoxophosphate (V)	87	(88.8%)	83	(83.8%)
Calcium tetraoxophosphate (V)	85	(86.7%)	83	(83.8%)
Ammonium sulphide	83	(84.7%)	90	(90.9%)

From Table 24, it was only in the compound Iron (III) trixoxocarbonate (IV) that 49.0% SHS 1 students were able to write it constituent ions. In all the other compounds less than 40.0% of the students were able to do so and with less than 10.0% in some of the compounds.

Concerning writing of chemical equations of inorganic reactions, students were given six statement reactions on combination, displacement and metathesis reactions and students were expected to translate these into balanced equations in symbols. Each correct balanced equation carried 1 mark. The performances of all the students (3 SHS 1 and 3 SHS 2 classes) who took part in the chemical equations pre-test are shown in Tables 18-22 with details in Appendices B2-N14 but the performances of SHS 2A and SHS 1A are shown in Table 25.

Table 25 -*Initial Performances of SHS 2A and SHS 1A Science Classes on Writing of Chemical Equations in the Pre-test*

	SHS 2A and SHS 1A Science Classes			
	2A (N = 36)		1A (N = 25)	
Questions	Mean	SD	Mean	SD
1.	0.21	0.41	0.20	0.41
2.	0.17	0.38	0.20	0.41
3.	0.07	0.26	0.04	0.20
4.	0.21	0.41	0.36	0.49
5.	0.07	0.26	0.04	0.20
6.	0.14	0.35	0.00	0.00

From Table 25, none of SHS 2A and SHS 1A classes obtained even 1 mark out of the total of 6 marks in the chemical equations pre-test painting another picture of poor performance.

From the detail results at Appendices B2-N14 60.6% of SHS 2 students could not write the balanced equation for simple combination reaction between: Aluminium metal ion and fluoride ion to form aluminium fluoride. Out of the 60.6%, 21.20% of them wrote the equation: $Al^{3+} + F^{-} \longrightarrow AlF_3$ and 9.1% of them wrote it as: $Al + 3F \longrightarrow AlF_3$. The other 30.3% students gave various wrong answers as shown in Appendix B2. Also 76.5% SHS 1 students could not write the balanced equation for the same reaction and majority (26.7%) of those who could not write the equation wrote the equation as: $Al + F_3 \longrightarrow AlF_3$. Another 21.3% of them wrote the equation: $Al + Fl \longrightarrow AlFl_3$ as shown in Appendix I9. For the chemical equation of the reaction between: Iron (II) metal ion and fluoride ion to form iron (II) fluoride, 68.7% SHS 2 students could not write the balanced chemical equation for the reaction and out of the 68.7%, 35.3% of them wrote the equation as: $Fe^{2+} + F^{-} \longrightarrow Fe_2F$

Again, 76.5% SHS 1 students could not write the balanced equation for the above reaction and out of the 76.5%, 34.7% of them wrote it as: $F_e + F_2 \longrightarrow FeF_2$ and 16.0% wrote it as: $Fe_2 + Fl \longrightarrow FeFl_2$ For the reaction between: Potassium hydroxide and tetraoxophosphate (V) acid to form potassium tetraoxophosphate (V) and water, 75.8% SHS 2 students could not write balanced equation for this reaction and 95.9% SHS 1 students could not perform the same task. From Appendices E5 and K11, 89.3% of SHS 2 students and 93.6% of SHS 1 students wrote the correct formula for Potassium hydroxide however, their impediment was the correct formula for tetraoxophosphate (V) acid. In the case of the reaction between Iron (II) metal ion and Copper (II) tetraoxosulphate (VI) to form Iron (II) tetraoxosulphate (VI) and Copper (II) metal, 30 out of 61 SHS 2 students who could not perform the task correctly wrote the equation as:

$$Fe_2 \quad + \quad CuSO_4 \longrightarrow Fe_2SO_4 \quad + \quad Cu_2$$

And 33 out of 68 SHS 1 students who could not write the equation wrote a similar equation as: $Fe_2 \quad + \quad Cu_2SO_4 \longrightarrow Fe_2SO_4 \quad + \quad Cu_2$

as shown in Appendices F6 and L12.

It was obvious from students' responses that the difficulties they had in writing chemical formulae posed the major problem for them in writing correct chemical equations. Incorrect formulae of ions/radicals, poor knowledge of valency and in some cases wrong symbols of elements were among the difficulties they encountered.

Performance of SHS 1A and SHS 2A Science Students in the Various Post-tests During Development of the Teaching and Learning Material

Research question 3 investigated how the SHS 1A and SHS 2A Science Students performed in the various post-tests during development of the teaching and learning material. Chemical formulae post-test 1 was an equivalent form of the Chemical formulae pre-test. Again, each correct item carried 1 mark and so the chemical formulae post-test 1 carried a total of 45 marks. The performances of SHS 1A and SHS 2A in the chemical formulae post-test 1 are shown in Table 26.

Table 26- *Performances of SHS 1A and SHS 2A Science Classes on Writing of Chemical Formulae in Post-test 1*

Question	SHS 1A (N=25)		SHS 2A (N=36)	
	Mean	SD	Mean	SD
a. (1-9)	4.77	3.82	4.59	3.87
b. (1-9)	4.59	3.79	4.41	3.83
c. (1-9)	4.50	3.77	4.32	3.77
d. (1-9)	4.50	3.77	4.32	3.77
e. (1-9)	4.68	3.78	4.32	3.79

From Table 26, the general performance of the two classes in the chemical formulae post-test 1 was average. This is because SHS 1A scored a class mean of 4.61 with standard deviation (SD) of 3.79 compared to mean score of 3.14 with SD of 4.91 in the pre-test. SHS 2A scored mean mark of 4.39 with standard deviation of 3.81 compared to mean mark of 1.37 and SD of 2.70 in the pre-test. Also SHS 1A had a raw score of 4.5 and a little above it in questions a. (1 – 9), b. (1 – 9), c. (1 – 9), d. (1 – 9) and e. (1 – 9) which carried a total of 9 marks each. SHS 2 also scored a little above 4.5 in a. (1 – 9) and came so close to 4.5 in b. (1 – 9), c. (1 – 9), d. (1 – 9) and e. (1 – 9).

Considering the compound Mercury (I) oxide, (see Appendix C for items) only 22.2% SHS 2 students and 20.0% SHS 1 students wrote the correct formula of the compound. In the case of SHS 2, the number even dropped to 19.4% in the (c), (d) and (e) aspects of the question (see Appendix C). The reason behind this was their inability to write the correct symbol of mercury. For the compound Barium tetraoxomanganate (VII) the performance of the students was also not good. This is because, only 33.3% of SHS 2 students and 32.0% SHS 1 students could write the correct chemical formula of the compound and these numbers even dropped in the (b), (c), (d) and (e) aspects of the question. The major problem here was inability to write the correct symbol of barium element. Considering the compound Potassium tetraoxochromate (VI) 52.0% SHS 1 students were able to write the correct formula but only 38.9% SHS 2 students could do the same. The rest of the students could not write the formula of the compound because they could not write the formula of tetraoxochromate (VI) ion correctly. However, for the compound, Beryllium hydroxide, all the SHS 2 and SHS 1 students wrote the correct formula and also answered all the sub questions correctly. Despite the fact that both classes performed averagely in the chemical formulae post-test 1, it was an improvement over their performance in the pre-test (see Table 23).

The performances of SHS 1A and SHS 2A science classes in the chemical equations post-test 1 is shown in Table 27.

Table 27-*Performances of SHS 1A and SHS 2A Science Classes on Writing of Chemical Equations in Post-test 1*

Question	SHS 1A (N=25)		SHS 2A (N=36)	
	Mean	SD	Mean	SD
1.	0.60	0.500	0.81	0.401
2.	0.56	0.507	0.89	0.319
3.	0.80	0.408	0.69	0.467
4.	0.64	0.490	0.69	0.467
5.	0.60	0.500	0.61	0.494
6.	0.52	0.510	0.56	0.504

From Table 27, out of the total mark of 6 in the chemical equations post-test 1 SHS 1A class scored mean mark of 0.62 with SD of 0.49 compared to mean score of 0.14 with SD of 0.29 in the pre-test. Likewise, SHS 2A class scored mean mark of 0.71 with SD of 0.44 in post-test 1 compared to mark of 0.15 with SD of 0.35 in the pre-test.

Both classes obtained more than 50% in all the questions (see Appendix D for items) in chemical equations post-test 1 with SHS 2 school A obtaining 89.7% in question 2 and SHS 1 school A obtaining 80.0% in question 3. In the pre-test, it was realised that the nitride ion was not familiar to the students but after post-test 1, 79.3% SHS 2 and 60.0% SHS 1 students were able to write the correct formula of Silver nitride. Also in the pre-test, only 33.3% of SHS 2 students and 32.0%

SHS 1 students could write the correct chemical formula of Barium tetraoxomanganate (VII) in a reaction that involved this formula however, in the post-test 1, 55.2% SHS 2 and 52.0 SHS 1 students were able to translate a statement reaction involving Barium metal ion and trioxocarbonate (IV) acid into a balanced equation in symbols.

The performances of the two classes in the chemical formulae post-test 2 are shown in Table 28.

Table 28-*Performances of SHS 1A and SHS 2A Science Classes on Writing of Chemical Formulae in Post-test 2*

	SHS 1A (N=25)		SHS 2A (N=36)	
Question	Mean	SD	Mean	SD
a. (1-9)	6.30	3.78	6.48	3.51
b. (1-9)	6.48	3.33	6.48	3.51
c. (1-9)	6.48	3.33	6.48	3.51
d. (1-9)	6.48	3.33	6.48	3.51
e. (1-9)	6.48	3.33	6.48	3.51

From Table 28, the general performance of the two classes in the chemical formulae post-test 2 was better than their performance in post-test 1. This is because SHS 1A scored a class mean mark of 6.44 with standard deviation (SD) of 3.4 compared to class mean score of 4.61 with standard deviation (SD) of 3.79 in the post-test 1. Also, SHS 2A scored class mean of 6.48 with standard deviation of 3.51 compared to mean score of 4.39 with standard deviation of 3.81 in the post-test 1. Also, out of 9 marks each for the sub-questions a. (1 – 9), b. (1 – 9), c. (1 – 9), d. (1 – 9) and e. (1 – 9), SHS 1A scored 6.30 in a. (1 – 9) and 6.48 in the rest. SHS 2A scored 6.48 in all these sub-questions.

In post-test 2, exactly 50.0% of SHS 2 and 48.0% of SHS 1 students wrote the correct formula of Aluminium trioxosulphate (IV) (see Appendix E for items) and exactly the same number of students had the sub-questions correct. The difficulty encountered by the rest of the students who could not perform the same tasks was that they had the valency of trioxosulphate (IV) ion wrong. Also in Barium tetraoxophosphate (V), 50.0% of SHS 2 and 40.0% of SHS 1 students got it correct. The main reason why the other students could not get it correct was that they used wrong valency of tetraoxophosphate (V) ion. It was realized in the pre-test that the tetraoxophosphate (V) ion was highly not familiar to the students hence their performance in Barium tetraoxophosphate (V) in post-test 2 was an improvement over the post-test 1. Also in Copper (II) trioxosulphate (IV), 50.0% SHS 2 and 48.0 SHS 1 had it correct. Again, the rest did not get it because they used wrong valency of trioxosulphate (IV) ion.

The performances of the two classes in the chemical equations post-test 2 are shown in Table 29.

Table 29-*Performances of SHS 1A and SHS 2A Science Classes on Writing of Chemical Equations in Post-test 2*

	SHS 1A (N=25)		SHS 2A (N=36)	
Question	Mean	SD	Mean	SD
1.	0.84	0.37	0.94	0.23
2.	0.92	0.28	0.94	0.23
3.	0.64	0.49	0.86	0.35
4.	0.96	0.20	0.92	0.28
5.	0.84	0.37	0.97	0.17
6.	1.00	0.00	1.00	0.00

From Table 29, SHS 1A class scored mean mark of 0.87 with SD of 0.29 compared to 0.62 with SD of 0.45 in the post-test 1. Likewise, SHS 2A class scored mean mark of 0.91 with SD of 0.21 compared to mean mark of 0.71 with SD of 0.44 in the post-test 1.

The performance of SHS 1A and SHS 2A in the chemical equations post-test 2 was higher than their performance in the chemical formulae post-test 2 because apart from question 3 (see Appendix F for items) where SHS 1 students scored 64.0%, both SHS 1 and SHS 2 students scored more than 80.0% in the rest of the questions with SHS 2A students scoring 100.0% in questions 1, 2, 4 and 6. It therefore appeared after post-test 2 that SHS 2 students were leading the SHS 1 students in terms of performance. Also, the performance of both classes in the two topics for post-test 2 was much better than their performance in post-test 1.

The performances of the two classes in the chemical formulae post-test 3 are shown in Table 30.

Table 30-*Performances of SHS 1A and SHS 2A Science Classes on Writing of Chemical Formulae in Post-test 3*

	SHS 1A (N=25)		SHS 2A (N=36)	
Question	Mean	SD	Mean	SD
a. (1-9)	8.10	1.80	8.28	1.26
b. (1-9)	8.10	1.80	8.28	1.26
c. (1-9)	7.92	1.98	7.83	2.07
d. (1-9)	7.92	1.98	7.83	2.07
e. (1-9)	7.92	1.98	7.83	2.07

From Table 30, chemical formulae post-test 3 results for both classes was better than their results in post-tests 1 and 2. This is because SHS 1A scored class mean mark of 7.99 with standard deviation (SD) of 1.90 compared to mean score of 6.44 with standard deviation (SD) of 3.42 in the post-test 2. Also, SHS 2A scored class mean mark of 8.01 with standard deviation of 1.75 compared to mean score of 6.48 with standard deviation of 3.51 in the post-test 2. Besides, out of 9 marks each for the sub-questions a. (1 – 9), b. (1 – 9), c. (1 – 9), d. (1 – 9) and e. (1 – 9), SHS 1A scored mean of 8.10 in a. (1 – 9) and b. (1 – 9) and 7.92 in the other three sub-questions. Also, SHS 2A had a mean score of 8.28 in a. (1 – 9) and b. (1 – 9) and 7.83 in the other three sub-questions.

For post-test 3, both SHS 1A and SHS 2A students scored 80.0% and beyond in items 1, 2, 3, 4 (a), (b), 6, 7 and 9 for the chemical formulae (see Appendix G for items) with SHS 2 students scoring 100.0% in items 1, 2, 3, 6 and 7 and SHS 1 students also scoring 100.0% in questions 2, 4, 6 and 7. At this stage of developing the teaching and learning material, about 80.0% - 100.0% of the students could write the chemical formulae of compounds like Lithium nitride, Iron (III) sulphide, Lead (II) trioxocarbonate (IV), Ammonium tetraoxosulphate (VI), Copper (II) fluoride, Beryllium hydroxide and Zinc trioxocarbonate (IV). At this stage in the development of the teaching and learning material, it became clear that once the student gets the formula of the ion and its valency correctly, the teaching and learning material helps the student to combine the ions and get the correct formula.

The chemical equations results of post-test 3 for the two classes are shown in Table 31.

Table 31-*Performances of SHS 1A and SHS 2A Science Classes on Writing of Chemical Equations in Post-test 3*

Question	SHS 1A (N=25)		SHS 2A (N=36)	
	Mean	SD	Mean	SD
1.	1.00	0.00	0.97	0.17
2.	0.92	0.28	1.00	0.00
3.	1.00	0.00	1.00	0.00
4.	0.96	0.20	1.00	0.00
5.	0.84	0.37	0.97	0.17
6.	0.80	0.41	1.00	0.00

From Table 31, SHS 1A class scored mean of 0.92 with SD of 0.21 in the chemical equations post-test 3 compared to class mean mark of 0.87 with SD of 0.29 in the post-test 2. Also, SHS 2A class scored class mean of 0.99 with SD of 0.06 compared to mean mark of 0.94 with SD of 0.21 in the post-test 2. Furthermore, in the chemical equations post-test 3, the SHS 2 students scored between 96.0% - 100.0% in all the six items (see Appendix H) and SHS 1 students also scored between 80.0% -100.0% in all the six items, an indication that students performance in chemical equations post-test 3 was the best compared to the pre-test and the two post-tests.

Performance of the Validation SHS 1 Science Students in the Pre-test and Post-test during Validation of the Teaching and Learning Material Already Developed.

After the development of the teaching and learning material in this study, the already developed material was validated using another SHS 1 class which had not been taught at the time the study was conducted. Research question 4 investigated how this validation SHS 1A class performed in the pre-test and the post-test conducted during validation of the teaching and learning material. The items in the Chemical formulae and chemical equations pre-test and post-test were equivalent forms of the tests used in the development stage. The performance of the validation class in the chemical formulae pre-test is shown in Table 32.

From Table 32, the general performance of the validation SHS 1 class in the chemical formulae pre-test was very poor. This is because the class scored a mean mark of 1.16 in the chemical formulae validation pre-test with standard deviation of 2.45. Each of the sub-questions a(1 – 9), b. (1 – 9), c. (1 – 9), d. (1 – 9) and e. (1 – 9) carried a total mark of 9 marks each however, the class could not score a mean mark of 2 in any of the sub-questions. Again, sub-questions c. (1 – 9), d. (1 – 9) produced the worst mean marks. This shows that knowledge of subscripts of constituent ions and what they mean is a problem among SHS 1and 2 students.

Table 32-*Performance of Validation SHS 1 Science Class on Writing of Chemical Formulae in Validation Pre-test*

Question	SHS 1 (N = 40)	
	Mean	SD
a. (1-9)	1.48	2.802
b. (1-9)	1.98	3.056
c. (1-9)	0.63	1.842
d. (1-9)	0.55	1.728
e. (1-9)	1.18	2.319

The pre-test results of validation chemical formulae were nothing to write home about. For the compound Iron (III) trixoxocarbonate (IV), (see Appendix I for items) only 9 students out of 40 were able to write the correct chemical formula for it. Out of the 31 students who could not write the formula of the compound, 22 (71.0%) wrote the formula as Fe_3CO_3. Also 6 of them wrote it as $FeCO_3$ and 3 wrote it as Fe_3C. For the compound Silver nitride, only 5.0% out of the 40 students were able to write the correct chemical formula of the compound. Out of the number who could not write the correct formula of Silver nitride, 21 (55.3%) wrote it as $AgNO_3$, 7 wrote it as $AgNO_2$ and 10 students gave no response. Considering the compound Iron (III) tetraoxosulphate (VI) only 15% of the students wrote the correct formula for this compound. Out of the number who could not, 18 (52.9%) wrote the formula as Fe_3S_6, 8 wrote it as Fe_3SO_4 and 8 gave no response. Also only 15.0% of the students could write the chemical formula of Ammonium trioxocarbonate (IV) and out of those who could not write the correct formula, 25 (73.5%) wrote the formula of the compound as NH_4CO_3, 5 students wrote the formula as NH_3CO_3 and 4 gave no response. For the compound Aluminium tetraoxosulphate (VI), out of the 30 students, who could not write its formula, 18 gave the formula as $AlSO_4$, 6 students wrote the formula as AlS_4 and 6 students gave no response. Out of the 31 students who could not write the chemical formula of Ammonium sulphide, 28 (90.3%) of them wrote the formula as NH_4S and the remaining 3 gave no response. But for the compounds Copper (II) tetraoxophosphate (V) and Calcium tetraoxophosphate (V) the students scored 0.0%. In the case of Copper (II) tetraoxophosphate (V), no student attempted any formula and for Calcium tetraoxophosphate (V), the only thing the students could write was the symbol of Ca.

The performance of the validation SHS 1 class in the validation chemical equations pre-test is shown in Table 33. From Table 33, the validation SHS 1A class scored a class mean mark as low as 0.12 with standard deviation of 0.24, an indication of a very poor performance. From Table 33, it is clear that out of 40 students in the validation class, no student got items 3 and 6 correctly (see Appendix J for items). Also less than 21.0% of the students scored items 1 and 4 correctly. Finally, less than 18.0% scored item 2 correctly and less than 7.0% scored item 5 correctly.

Table 33-*Performance of Validation SHS 1 Science Class on Writing of Chemical Equations in Validation Pre-test*

Question	SHS 1 (N = 40)	
	Mean	SD
1.	0.20	0.41
2.	0.33	0.47
3.	0.00	0.00
4.	0.15	0.36
5.	0.05	0.22
6.	0.00	0.00

Results of validation chemical formulae post-test are shown in Table 34. From Table 34, chemical formulae validation post-test results for validation SHS 1 class was far better than their results in the pre-test. This is because the class scored a mean mark of 8.25 with standard deviation (SD) of 2.07 compared to a mean score of 1.16 with standard deviation (SD) of 2.35 in the pre-test. Besides, for the sub-questions a.(1 – 9), b. (1 – 9), c. (1 – 9), d. (1 – 9) and e. (1 – 9), the validation SHS 1 class scored a mean mark of 8.25 out of 9.0 marks in each of these sub-questions compared to mean scores of 1.48, 1.98, 0.63, 0.55 and 1.18 respectively in these sub-questions in the pre-test.

Table 34-*Performance of Validation SHS 1 Science Class on Writing of Chemical Formulae in Validation Post-test*

Question	SHS 1 (N = 40) Mean	SD
a. (1-9)	8.25	2.07
b. (1-9)	8.25	2.07
c. (1-9)	8.25	2.07
d. (1-9)	8.25	2.07
e. (1-9)	8.25	2.07

The results of chemical formulae validation post-test was good because apart from item 9 (see Appendix K for items) in which the validation class scored 52.5%, the validation class scored between 70.0% - 100.0% in items 1-8. Considering the compound, Calcium hydrogen trioxosulphate (IV), 72.5% of the students got this item correct. The remaining 27.5% of the students did not get the formula correct because they used wrong valency for hydrogen trioxosulphate (IV) ion. For the compound Barium tetraoxomanganate (VII), 32 students out of 40 gave the correct chemical formula for this compound. The remaining 8 students did not get the formula correct because they used wrong valency of tetraoxomanganate (VII) ion.

For item 3, Sodium tetraoxophosphate (V), 33 (82.5%) of the students got the chemical formula of this compound correct. In the validation pre-test of the same students, it was realized that students scored 0.0% in the compounds: Copper (II) tetraoxophosphate (V) and Calcium tetraoxophosphate (V) largely because the tetraoxophosphate (V) ion was not familiar to the students. After tuition with the already developed teaching and learning material for four weeks, the same students came out with such an impressive performance. For the compound Lithium hydrogen tetraoxosulphate (VI), 35 out of 40 students got this item correct. The remaining 5 students had it wrong because they used wrong valency for the hydrogen tetraoxosulphate (VI) ion. For the compound Copper (I) nitride, the performance of the students was very good in the sense that in the validation pre-test, the same group of students were given the compound Silver nitride and it turnout that only 5.0% of the students were able to write the chemical formula of the compound. However after four weeks of tuition with the teaching and learning material developed, 90.0% of the same students were able to write the chemical formula of Silver nitride. With regard to the compounds Aluminium chloride and Potassium heptaoxodichromate (VI), the performance of the students was also very good because all the 40 students used for validation wrote the correct chemical formula for Aluminium chloride and 90.0% of the students also wrote the correct chemical formula for Potassium heptaoxodichromate (VI).

The performance of the validation SHS 1 class in the chemical equations validation post-test are shown in Table 35.

Table 35-*Performance of Validation SHS 1 Science Class on Writing of Chemical Equations in Validation Post-test*

Question	SHS 1 (N = 40)	
	Mean	SD
1.	1.00	0.00
2.	1.00	0.00
3.	0.70	0.46
4.	0.75	0.44
5.	0.90	0.30
6.	0.90	0.30

From Table 35 the performance of the validation SHS 1 class in the validation chemical equations post-test was very good and again far better than their pre-test performance. This is because the class scored a mean mark of 0.88 in the chemical equations validation post-test with standard deviation of 0.25 compared to a low mean score of 0.12 with standard deviation of 0.24 in the validation pre-test. From Table 35, all the 40 students in the validation class, scored items 1 and 2 correctly. The performance of the students in items 2, 3, 4, 5 and 6 was as well very good.

For the reaction between iron (III) metal ion with trioxocarbonate (IV) ion to form iron (III) trioxocarbonate (IV) (see Appendix L for items) 30 (75.0%) of the students in the validation class were able to write the correct balanced equation for this reaction. The remaining 25.0% wrote wrong equation because they used wrong valency of trioxocarbonate (IV) ion. For the reaction between mercury (I) ion with oxide ion to form mercury (I) oxide, 87.5% of the students wrote the correct equation. The remaining 12.5% of the students could not write the equation because they used wrong symbol for mercury. Considering the reaction between iron (III) oxide with trioxocarbonate (IV) acid to form iron (III) trioxocarbonate (IV) and water, 25 (62.5%) of the students wrote the correct equation. The main difficulty on the part of those who could not write the equation was their inability to write the correct formula for trioxocarbonate (IV) acid. For the reaction between lithium hydroxide with tetraoxophosphate (V) acid to form lithium tetraoxophosphate (V) and water, the equation was correctly written by 70.0% of the students. Writing the correct formula for lithium tetraoxophosphate (V) was the main difficulty for the 30.0% who could not write the equation. Reaction of sodium metal ion with aluminium trioxonitrate (V) to form sodium trioxonitrate (V) and aluminium metal was correctly written by all 40 students. Lastly for the reaction between aluminium metal ion with lead (II) tetraoxosulphate (VI) to form aluminium tetraoxosulphate (VI) and lead metal, 72.5% of the students performed the task correctly. The remaining 27.5% of the students could not perform the task correctly because they could not write the correct formula for lead (II) tetraoxosulphate (VI).

Determination of the Difference in the Degree of Changes in Conceptions of SHS 1A and SHS 2A Science Students between their Pre-test and post- test 3 on Writing of Chemical Formulae and Chemical Equations during Development of the Teaching and Learning Material in this study.

Hypotheses 1 and 3 sought to investigate whether there was no statistically significant difference in the degree changes in conceptions of SHS 1A and SHS 2A science students between their pre-test and post-test 3 on writing of chemical formulae during development of the teaching and learning material in this study.

To test these hypotheses, analysis was done to find out the degree of change of SHS 1A and SHS 2A science students' alternative conceptions in chemical formulae from the pre-test to the post-test 3. The number and percentages of students with alternative conceptions at the pre-test and after the post-test 3 were also determined. Furthermore students who experienced no change in their correct conceptions as well as those who experienced no change in their wrong conceptions were also determined.

To determine the degree of changes in students' alternative conceptions in chemical formulae from the pre-test to the post-test 3, the McNemar chi square test for significance of changes was used. The degree of changes in SHS 1A and SHS 2A science students' alternative conception from the pre-test to the post-test 3 for each question was calculated using the McNemar formula and presented in Table 36 (see Appendix O15 for extended version of Table 36).

Table 36-*Changes in conceptions of SHS 2A and SHS 1A Science Classes on Writing of Chemical Formulae from Pre-test to Post-test 3*

	SHS 2A Class [N = 36]			SHS 1A Class [N = 25]		
Question	Pretest	Posttest 3	χ^2	Pretest	Posttest 3	χ^2
1(a)	16(44.4)	2(5.6)	12.071*	13(52.0)	1(4.0)	8.643*
1(b)	15(41.7)	2(5.6)	11.077*	11(44.0)	1(4.0)	6.750*
1(c)	15(41.7)	5(13.9)	5.786*	12(48.0)	4(16.0)	4.083*
1(d)	15(41.7)	5 (13.9)	5.786*	12(48.0)	2(8.0)	4.083*
1(e)	18(50.0)	6(16.7)	5.786*	13(52.0)	2(8.0)	6.667*
2(a)	16(44.4)	0(0.0)	14.063*	11(44.0)	0(0.0)	9.091*
2(b)	16(44.4)	0(0.0)	14.063*	12(48.0)	2(8.0)	8.100*
2(c)	15(41.7)	0(0.0)	13.067*	12(48.0)	2(8.0)	8.100*
2(d)	15(41.7)	0(0.0)	13.067*	12(48.0)	2(8.0)	8.100*
2(e)	15(41.7)	0(0.0)	13.067*	12(48.0)	2(8.0)	8.100*
3(a)	25(69.4)	0(0.0)	23.040 *	20(80.0)	2 (8.0)	13.136 *
3(b)	25(69.4)	0(0.0)	23.040*	20(80.0)	2(8.0)	13.136*
3(c)	25(69.4)	0(0.0)	23.040*	20(80.0)	2(8.0)	13.136*
3(d)	25(69.4)	0(0.0)	23.040*	20(80.0)	2(8.0)	13.136*
3(e)	25(69.4)	0(0.0)	23.040*	20(80.0)	2(8.0)	13.136*

Figures in parenthesis are percentages *Significant at $\chi^2 \geq 3.84$

Table 36 Cont'd-*Changes in conceptions of SHS 2A and SHS 1A Science Classes on Writing of Chemical Formulae from Pre-test to Post-test 3*

	SHS 2A Class [N = 36]			SHS 1A Class [N = 25]		
Question	Pretest	Posttest 3	χ^2	Pretest	Posttest 3	χ^2
4(a)	16(44.4)	2(5.6)	12.071*	10(40.0)	0(0.0)	8.100*
4(b)	12(33.3)	0(0.0)	10.083*	10(40.0)	0(16.0)	8.100*
4(c)	12(33.3)	2(5.6)	5.786 *	9(36.0)	0(0.0)	7.111*
4(d)	12(33.3)	2(5.6)	5.786*	9(36.0)	0(0.0)	7.111*
4(e)	12(33.3)	2(5.6)	5.786*	9(36.0)	0(0.0)	7.111*
5(a)	20(55.6)	2(5.6)	13.136*	15(60.0)	2(8.0)	8.471*
5(b)	19(52.8)	2(5.6)	12.190*	15(60.0)	2(8.0)	8.471*
5(c)	19(52.8)	2(5.6)	12.190*	15(60.0)	2(8.0)	8.471*
5(d)	19(52.8)	2(5.6)	12.190*	15(60.0)	2(8.0)	8.471*
5(e)	19(52.8)	2(5.6)	12.190*	15(60.0)	2(8.0)	8.471*
6(a)	12(33.3)	0(0.0)	10.083*	8(32.0)	0(0.0)	6.125*
6(b)	9(25.0)	0(0.0)	7.111*	7(28.0)	0(0.0)	5.143*
6(c)	9(25.0)	0(0.0)	7.111*	9(36.0)	2(8.0)	5.143*
6(d)	9(25.0)	0(0.0)	7.111*	9(36.0)	2(8.0)	5.143*
6(e)	9(25.0)	0(0.0)	7.111*	7(28.0)	7(28.0)	5.143*

Figures in parenthesis are percentages *Significant at $\chi^2 \geq 3.84$

Table 36 Cont'd-*Changes in conceptions of SHS 2A and SHS 1A Science Classes on Writing of Chemical Formulae from Pre-test to Post-test 3*

	SHS 2A Class [N = 36]			SHS 1A Class [N = 25]		
Question	Pretest	Posttest 3	χ^2	Pretest	Posttest 3	χ^2
7(a)	20(55.6)	0(0.0)	18.050*	12(48.0)	0(0.0)	10.083*
7(b)	20(55.6)	0(0.0)	18.050*	12(48.0)	0(0.0)	10.083*
7(c)	20(55.6)	0(0.0)	18.050*	12(48.0)	0(0.0)	10.083*
7(d)	20(55.6)	0(0.0)	18.050*	12(48.0)	0(0.0)	10.083*
7(e)	20(55.6)	0(0.0)	18.050*	12(48.0)	0(0.0)	10.083*
8(a)	18(50.0)	12(3.3)	2.500	15(60.0)	12(4.8)	0.572
8(b)	17(47.2)	10(2.7)	3.273	15(60.0)	12(4.8)	0.572
8(c)	15(41.7)	9(2.7)	1.778	15(60.0)	12(4.8)	0.572
8(d)	15(41.7)	9(2.7)	1.778	15(60.0)	12(4.8)	0.572
8(e)	15(41.7)	9(25.0)	1.778	15(60.0)	13(36.1)	0.125
9(a)	32(88.9)	0(0.0)	30.031*	22(88.0)	1(4.0)	17.391*
9(b)	32(88.9)	0(0.0)	30.031*	22(88.0)	1(4.0)	17.391*
9(c)	32(88.9)	0(0.0)	30.031*	22(88.0)	1(4.0)	17.391*
9(d)	32(88.9)	0(0.0)	30.031*	22(88.0)	1(4.0)	17.391*
9(e)	32(88.9)	0(0.0)	30.031*	22(88.0)	1(4.0)	17.391*

Figures in parenthesis are percentages *Significant at $\chi^2 \geq 3.84$

Changes in conceptions of SHS 2A and SHS 1A science classes on writing of chemical formulae from pre-test to post-test 3 was generally very good in the sense that high percentages of students who had alternative conceptions at the pre-test had their numbers reduced drastically even in some items to 0.0% after the post-test 3. Secondly from the pre-test to post-test 3, the changes in conceptions of both classes from their alternative conception at the pre-test to the scientifically accepted conception after the post-test 3 was statistically significant in eight out of the nine items of the chemical formulae post-test 3.

Considering item 9(a-e) of the chemical formulae post-test 3, 88.9% of SHS 2A students and 88.0% of SHS 1A students who had alternative conception at the pre-test had their numbers reduced respectively to 0.0% and 4.0% and 4 SHS 2A and 2 SHS 1A students who had the correct scientifically accepted conception at the pre-test did not experience any change in their conception after post-test 3 (see Appendix O15 for full details). This change in conceptions was statistically significant ($\chi^2 = 30.031$ for SHS 2 and $\chi^2 = 17.391$ for SHS 1). Also in item 3, 69.4% SHS 2 students and 80.0% SHS 1A students who had alternative conception at the pre-test had their numbers reduced respectively to 0.0% and 8.0%. This change in conception was as well statistically significant with ($\chi^2 = 23.040$ for SHS 2 and $\chi^2 = 13.136$ for SHS 1). This pattern of change in alternative conception for the scientifically accepted conception from the pre-test to the post-test 3 was similar to all the other items. The only item in which statistically significant change in conception was not recorded was in item 8 and the reason was that in this item, the category of both SHS 2A SHS 1A students who did not experience any change in their conception from the pre-test to the post-test 3 was more than those who changed their conception.

Specifically speaking, the major difficulty students faced at the pre-test was that majority of them did not know the meaning of Roman numerals in brackets of IUPAC names. Few students took those Roman numerals to be the number of element or radical in whose front the number is written. For example in compound like iron (III) trixoxocarbonate (IV), iron (III) was written as Fe_3 and trixoxocarbonate (IV) as $(CO_3)_4$. In copper (II) tetraoxophosphate (V), copper (II) was written as Cu_2 and tetraoxophosphate (V) $CuPO_4$ The concept of subscripts of constituent ions and even the term constituent ions was not familiar to the students even the SHS 2 students.

After post-test 3 and after six lessons including three iterations, students abandon these alternative conceptions and difficulties and the concept of constituent ions, constituent ions and their subscripts in compounds and valency of constituent ions became clear to the students.

Hypotheses 2 and 4 sought to investigate whether there was no statistically significant difference in the degree changes in conceptions of SHS 1A and SHS 2A science students between their pre-test and post-test 3 on writing of chemical equations during development of the teaching and learning material in this study.

Again, to determine the degree of changes in students' alternative conceptions in chemical equations from the pre-test to the post-test 3, the McNemar chi square test for significance of changes was used. The degree of changes in SHS 1A and SHS 2A science students' alternative conception from the pre-test to the post-test 3 for each question was calculated using the McNemar formula and presented in Table 37 (see Appendix P16 for extended version of Table 37).

Table 37-*Changes in conceptions of SHS 2A and SHS 1A Science Classes on Writing of Chemical Equations from Pre-test to Post-test 3*

	SHS 2A Class [N = 36]			SHS 1A Class [N = 25]		
Question	Pretest	Posttest	χ^2	Pretest	Posttest	χ^2
1	20(55.6)	0(0.0)	21.043*	15(60.0)	0(0.0)	13.067*
2	26(72.2)	0(0.0)	24.038*	14(56.0)	1(4.0)	9.600*
3	20(55.6)	0(0.0)	18.050*	20(80.0)	0(0.0)	18.050*
4	20(55.6)	0(0.0)	18.050*	16(64.0)	0(0.0)	11.523*
5	18(50.0)	1(2.8)	13.474*	15(60.0)	2(8.0)	8.471*
6	16(44.4)	0(0.0)	14.063*	13(52.0)	2(8.0)	6.667*

Figures in parenthesis are percentages *Significant at $\chi^2 \geq 3.84$

From Table 37 changes in conceptions of SHS 2A and SHS 1A science classes on writing of chemical equations from pre-test to post-test 3 was generally very good in the sense that majority of students in both classes who had alternative conceptions at the pre-test did not have any alternative conceptions after the post-test 3. Secondly from the pre-test to post-test 3, the changes in conceptions of both classes from their alternative conception at the pre-test to the scientifically accepted conception after the post-test 3 was statistically significant in all six items of the chemical equations post-test 3.

In item 1 of chemical equations post-test 3, 55.6% SHS 2A students who had alternative conceptions at the pre-test did not have any alternative conception after the post-test 3 compared to 60.0% SHS 1A students who did same. This change in conception of both classes from their alternative conception at the pre-test to the scientifically accepted conception after the post-test 3 was statistically significant for both classes ($\chi^2 = 21.043$ for SHS 2 and $\chi^2 = 13.067$ for SHS 1). For the same item, 13 SHS 2A and 10 SHS 1A students who did not have any alternative conception at the pre-test maintained their correct conception after post-test 3 (see Appendix P16). Considering item 2 of the chemical equations post-test 3, 72.2% of SHS 2A students and 56.0% SHS 1A students who had alternative conceptions at the pre-test had their numbers respectively reduced to and 0.0% and 4.0%. This change in conception of both classes from their alternative conception at the pre-test to the scientifically accepted conception after the post-test 3 was statistically significant for both classes with a large χ^2- value for SHS 2A class ($\chi^2 = 24.038$ for SHS 2 and $\chi^2 = 9.600$ for SHS 1). This pattern of change in conception of both classes from their alternative conception at the pre-test to the scientifically accepted conception after the post-test 3 is similar to all the other items.

Specifically speaking, the major difficulty students faced at the pre-test in chemical equations was poor knowledge of inorganic reaction. Students did not know that in an inorganic reaction: the cation of compound 1 reacts with the anion of compound 2 and the cation of compound 2 reacts with the anion of compound 1. The few students who knew this could not react these ions correctly due to poor knowledge of valency.

After post-test 3 and after six lessons including three iterations, students abandon these alternative conceptions and difficulties because the PCK material developed in this study was shaped differently to represent cations and anions and designed primarily to addresses students' problem with valency.

Determination of the Difference in the degree of Changes in Conceptions of Validation SHS 1 Science Students between their Pre-test and Post-test on Writing of Chemical Formulae and Chemical Equations during Validation of the Teaching and Learning Material Developed in this study

Hypotheses 5 and 6 sought to investigate whether there was no statistically significant difference in the degree of changes in conceptions of validation SHS 1 science students between their pre-test and post-test on writing of chemical formulae and chemical equations during validation of the teaching and learning material developed.

To determine the degree of changes in students' alternative conceptions in validation chemical formulae from the pre-test to the post-test, the McNemar chi square test for significance of changes was used. The degree of changes in validation SHS 1 science students' alternative conception in chemical formulae from the pre-test to the post-test for each question was calculated using the McNemar formula and presented in Table 38 (see Appendix Q17 for extended version of Table 38).

Table 38-*Changes in Validation Students' Conceptions in Chemical Formulae from Pre-test to Post-test*

	Validation SHS 1 Class [N = 40]		
Question	Pretest	Posttest	χ^2
1(a)	30(72.5)	4(10.0)	19.53*
1(b)	30(72.5)	4(10.0)	19.531*
1(c)	30(72.5)	5(12.5)	17.455*
1(d)	30(72.5)	5(12.5)	17.455*
1(e)	31(77.5)	3(7.5)	24.300*
2(a)	35(87.5)	3(7.5)	30.031*
2(b)	32(80.0)	3(7.5)	22.400*
2(c)	34(85.0)	4(10.0)	27.735*
2(d)	35(87.5)	3(7.5)	30.031*
2(e)	33(82.5)	2(5.0)	27.273*
3(a)	33(82.5)	2(5.0)	25.714*
3(b)	33(82.5)	2(5.0)	25.714*
3(c)	34(85.0)	2(5.0)	28.265*
3(d)	34(85.0)	3(7.5)	27.714*
3(e)	35(87.5)	2(5.0)	31.030*

Figures in parenthesis are percentages *Significant at $\chi^2 \geq 3.84$

Table 38 Cont'd-*Changes in Validation Students' Conceptions in Chemical Formulae from Pre-test to Post-test*

	Validation SHS 1 Class [N = 40]		
Question	Pretest	Posttest	χ^2
4(a)	35(87.5)	1(2.5)	30.250*
4(b)	35(87.5)	1(2.5)	30.250*
4(c)	36(90.0)	1(2.5)	33.029*
4(d)	36(90.0)	2(5.0)	30.250*
4(e)	36(90.0)	2(5.0)	30.250*
5(a)	36(90.0)	0(0.0)	34.028*
5(b)	36(90.0)	0(0.0)	34.028*
5(c)	36(90.0)	1(2.5)	31.243*
5(d)	37(92.5)	1(2.5)	34.028*
5(e)	36(90.0)	0(0.0)	34.028*
6(a)	40(100.0)	0(0.0)	38.025*
6(b)	40(100.0)	0(0.0)	38.025*
6(c)	40(100.0)	0(0.0)	38.025*
6(d)	40(100.0)	0(0.0)	38.025*
6(e)	40(100.0)	0(0.0)	38.025*

Figures in parenthesis are percentages *Significant at $\chi^2 \geq 3.84$

Table 38 Cont'd-*Changes in Validation Students' Conceptions in Chemical Formulae from Pre-test to Post-test*

Validation SHS 1 Class [N = 40]			
Question	Pretest	Posttest	χ^2
7(a)	36(90.0)	0(00.0)	34.028*
7(b)	36(90.0)	1(2.5)	31.243*
7(c)	36(90.0)	1(2.5)	31.243*
7(d)	37(92.5)	1(2.5)	34.028*
7(e)	37(92.5)	1(2.5)	34.028*
8(a)	30(75.0)	3(7.5)	21.806*
8(b)	31(77.5)	3(7.5)	24.300*
8(c)	31(77.5)	4(10.0)	21.806*
8(d)	32(80.0)	5(12.5)	21.806*
8(e)	31(77.5)	3(7.5)	24.300*
9(a)	26(65.0)	9(22.5)	10.240*
9(b)	26(65.0)	9(22.5)	10.240*
9(c)	26(65.0)	10(25.0)	8.654*
9(d)	25(62.5)	8(20.0)	10.240*
9(e)	24(60.0)	6(15.0)	12.042*

Figures in parenthesis are percentages *Significant at $\chi^2 \geq 3.84$

From Table 38, students' changes in their alternative conceptions for the scientifically accepted conceptions from the validation pre-test to the validation post-test were statistically significant for all 45 items of the chemical formulae post-test.

Considering item 1(a) of validation chemical formulae, from Table 38 and Appendix Q17, 72.5% of the validation SHS 1 students before tuition with the teaching and learning material had alternative conception but after tuition with the teaching and learning material already developed, these students abandon their alternative conception for the scientifically accepted conception though 3 students also developed alternative conception as a result of tuition with the teaching and learning material. Furthermore 7 students who had correct conception before tuition did not experience any change to their conception after the post-test. These changes in students' alternative conception for the scientifically accepted conception from the pre-test to the post-test were statistically significant for all the sub questions of item 1 (see Table 38 and Appendix Q17).

In question 2(a) of the chemical formulae, 87.5% of the students before tuition with the teaching and learning material at pre-test had alternative conception but after tuition with the teaching and learning material already developed, these numbers reduced statistically significantly to 7.5% after tuition with the teaching and learning material. This was because 80.0% of the students from the pre-test to the post-test abandon their alternative conception for the scientifically accepted conception and none of them developed alternative conception as a result of tuition with the teaching and learning material. In item 6, students change in their alternative conception for the scientifically accepted conception from pre-test to the post-test was 100.0%.

The degree of changes in validation SHS 1 science students' alternative conception in chemical equations from the pre-test to the post-test for each question was also calculated using the McNemar formula and presented in Table 39 (see Appendix R18 for extended version of Table 39).

Table 39-*Changes in Validation Students' Conceptions in Chemical Equations from Pre-test to Post-test*

	Validation SHS 1 Class [N = 40]		
Question	Pretest	Posttest	χ^2
1	40(100.0)	0(00.0)	38.025*
2	34(85.0)	4(10.0)	24.735*
3	31(77.5)	6(15.0)	18.581*
4	27(67.5)	7(17.5)	13.885*
5	32(80.0)	4(10.0)	22.781*
6	30(75.0)	5(12.5)	18.581*

Figures in parenthesis are percentages *Significant at $\chi^2 \geq 3.84$

From Table 39, it could also be seen that changes in students' alternative conceptions for the scientifically accepted conceptions for chemical equations from pre-test to post-test were statistically significant for all 6 items. With regard to item 1 of validation chemical equations from Table 39 and Appendix R18, all 40 students changed their alternative conception for the scientifically accepted conception from the pre-test to the post-test and this obviously was statistically significant. In item 2, out of the 40 students, 32 abandon their alternative conception for the scientifically accepted conception from the pre-test to the post-test, 4 students who had the correct conception before tuition with the teaching and learning material did not experience any change in their conception and 2 students developed alternative conceptions. From Table 39, change in students' alternative conception for the scientifically accepted conception from the pre-test to the post-test was also statistically significant in item 2. For item 3, 28 out of 40 students changed their alternative conception for the scientifically accepted conception, 6 students who had the correct conception before tuition did not experience any change in their conception and 3 students developed alternative conception as a result of the tuition with the teaching and learning material. The pattern of changes in students' alternative conceptions in item 3 is similar to the pattern of changes in their alternative conceptions in items 4, 5 and 6.

Determination of the Differences Between the Pre-test and the Post-test 3 results in the Writing of Chemical Formulae and Chemical Equations of SHS 1A and SHS 2A Science Students who were Taught with the Teaching and Learning Material Developed in this study.

Hypotheses 7 and 8 sought to find out any significant difference between the mean scores of SHS 1A and SHS 2A students pre-test results in chemical formulae before they were taught with the teaching and learning material and their post-test 3 results after they were taught in the development stage of the teaching and learning material. Students' pre-test results were compared to their post-test 3 results because the two happened to produce the worst and the best performances respectively from them. The results of the paired samples t-test analysis conducted for SHS 1A chemical formulae pre-test and post-test 3 are as shown in Table 40.

Table 40-*Paired-Samples t-test Results for SHS 1 Chemical Formulae Pre – test and Post-test 3*

Test	N	Mean	Mean Difference	SD	t	df	P
Pre-test	25	15.72		24.57			
			24.24		3.206	23	0.008*
Post-test 3	25	39.96		9.63			

*significant at $p < 0.05$

As shown in Table 40, the mean score of SHS 1A students performance in the post-test 3 of the chemical formulae (M = 39.96, SD = 9.63) was significantly higher than the mean score of their pre-test (M = 15.72, SD = 24.57), t(25) = 3.206, p = 0.008 with a very large effect size of 0.91. Hence we reject null hypotheses 1 and 7.

The results of the paired samples t-test analysis conducted for SHS 2A chemical formulae pre-test and post-test 3 are as shown in Table 41.

Table 41-*Paired-Samples t-test Results for SHS 2 Chemical Formulae Pre – test and Post-test 3*

Test	N	Mean	Mean Difference	SD	t	df	P
Pre-test	36	6.85		14.74			
			33.20		3.415	34	0.002*
Post-test 3	36	40.05		8.73			

*significant at $p < 0.05$

As shown in Table 41, the mean score of SHS 2A students performance in the post-test 3 of the chemical formulae (M = 40.05, SD = 8.73) was significantly higher than the mean score of their pre-test (M = 6.85, SD = 14.74), t(36) = 3.415, p = 0.002 with a large effect size = 0.80. Hence we reject null hypotheses 3 and 8.

Hypotheses 9 and 10 sought to find out any significant difference between the mean scores of SHS 1A and SHS 2A science students pre-test results in chemical equations before they were taught with the teaching and learning material and their post-test 3 results after they were taught in the development stage of the teaching and learning material. Students' pre-test results were compared to their post-test 3 and the results of the paired samples t-test analysis conducted for SHS 1A chemical equations pre-test and post-test 3 are as shown in Table 42.

Table 42-*Paired-Samples t-test Results for SHS 1 Chemical Equations Pre-test and Post-test 3*

Test	N	Mean	Mean Difference	SD	t	df	P
Pre-test	25	0.84		1.71			
			4.68		2.898	23	0.008*
Post-test 3	25	5.52		1.26			

*significant at $p < 0.05$

As shown in Table 42, the mean score of SHS 1A students performance in the post-test 3 of the chemical equations ($M = 5.52$, $SD = 1.26$) was significantly higher than the mean score of their pre-test ($M = 0.84$, $SD = 1.71$), $t(25) = 2.898$, $p = 0.008$ with a large effect size = 0.82. Hence we reject null hypotheses 2 and 9.

The results of the paired samples t-test analysis conducted for SHS 2A chemical equations pre-test and post-test 3 are as shown in Table 43. As shown in Table 43, the mean score of SHS 2A students performance in the post-test 3 of the chemical equations ($M = 5.94$, $SD = 0.33$) was significantly higher than the mean score of their pre-test ($M = 0.87$, $SD = 2.07$), $t(36) = 4.20$, $p = 0.001$ with a very large effect size = 0.99. Hence we reject null hypotheses 4 and 10.

Table 43-*Paired Samples t-test Results for SHS 2 Chemical Equations Pre-test and Post-test 3*

Test	N	Mean	Mean Difference	SD	t	df	P
Pre-test	36	0.87		2.07			
			5.07		4.20	34	0.001*
Post-test 3	36	5.94		0.33			

*significant at $p < 0.05$

Determination of the Differences Between the Pre-test and the Post-test results of Chemical Formulae and Chemical equations of the Validation SHS 1 Science Students during Validation of theTeaching and Learning Material.

Hypothesis 11 sought to find out any significant difference between the mean scores of validation SHS 1 science students pre-test results in chemical formulae before they were taught with the already developed teaching and learning material and their post-test results after they were taught in the validation of the already developed teaching and learning material. Students' pre-test results were compared to their post-test results and results of the paired samples t-test analysis conducted for the validation SHS 1 chemical formulae pre-test and post-test are as shown in Table 44.

Table 44-*Paired-Samples t-test Results for Validation SHS 1 Chemical Formulae Pre - test and Post-test*

Test	N	Mean	Mean Difference	SD	t	df	P
Pre-test	40	5.82		9.83			
			35.43		3.734	38	0.001*
Post-test	40	41.25		8.75			

*significant at $p < 0.05$

As shown in Table 44, the mean score of validation SHS 1 students performance in the post-test of validation chemical formulae (M = 41.25, SD = 8.75) was significantly higher than the mean score of their pre-test (M = 5.82, SD = 9.83), t(40) = 3.734, p = 0.001 with a large effect size of 0.83. Hence we reject null hypotheses 5 and 11.

Hypothesis 12 sought to find out any significant difference between the mean scores of validation SHS 1 science students pre-test results in chemical equations before they were taught with the already developed teaching and learning material and their post-test results after they were taught in the validation of the already developed teaching and learning material.

The results of the paired samples t-test analysis conducted for validation SHS 1 chemical equations pre-test and post-test are as shown in Table 45.

Table 45-*Paired-Samples t-test Results for Validation SHS 1 Chemical Equations Pre - test and Post-test*

Test	N	Mean	Mean Difference	SD	t	df	P
Pre-test	40	0.73		1.24			
			4.52		3.698	38	0.001*
Post-test 2	40	5.25		1.32			

*significant at $p < 0.05$

As shown in Table 45, the mean score of validation SHS 1 students performance in the post-test of validation chemical equations (M = 5.25, SD = 1.32) was significantly higher than the mean score of their pre-test (M = 0.73, SD = 1.24), t(40) = 3.698, p = 0.001 with a large effect size of 0.83. Hence we reject null hypotheses 6 and 12.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The purpose of this study was to develop a teaching and learning material for chemical formulae and chemical equations of inorganic compounds. This was achieved by pre-testing an SHS 1 science class and an SHS 2 science class to determine their initial difficulties after which they were taken through series of iterations and followed through to see how their conceptions of the two topics changed as they went through the iterations to develop the teaching and learning material. The study also sought the views of SHS chemistry teachers about issues concerning the teaching and learning of chemical formulae and chemical equations of inorganic compounds and highlights of the teachers' views were factored into the development of the teaching and learning material. The study sought to determine whether there was any significant difference between the pre-test and the final post-test results of both SHS 1 and 2 science students used to develop the teaching and learning material and to find how much they have gained from the pre-test to the final post-test. Finally, the study validated the teaching and learning material developed by pre-testing another SHS 1 science class from the population using the same pre-test items as before, teaching them with the already developed teaching and learning material and post-testing them.

Cross-sectional survey and one group pre-test-post-test experimental designs were used in which quantitative and qualitative methods were employed. The sample consisted of 98 SHS 1 science students with 38 boys and 60 girls, 99

SHS 2 science students comprising of 84 boys and 15 girls and 20 SHS chemistry teachers selected from the accessible population. The mean age of the SHS 1 students was 16.9 with standard deviation of 1.4 and the mean age of the SHS 2 students was also 16.9 with standard deviation of 1.2.

Key Findings

The following findings were identified in the study:

(1) The initial difficulties SHS 1 and SHS 2 science students have on writing of chemical formulae and chemical equations were:

(f) Students' inability to explain the meaning of Roman numerals in parenthesis of IUPAC names.

(g) Students' difficulty in writing correct formulae of ions of the elements especially in radicals.

(h) The concept of valency and the role it plays in the writing of chemical formulae is poorly understood by both SHS 1 and SHS 2 students.

(i) Students find it difficult to determine the constituent ions of ionic compounds let alone combining the ions to form a neutral compound.

(j) Students' difficulties in writing correct chemical formulae posed the major problem for them in writing correct chemical equations.

(2) Concerning the performance of SHS 1A and SHS 2A science students in the various post-tests during development of the teaching and learning material, the following findings were made:

(a) In the first post-test, that is after the first iteration where the teaching and learning material was used to teach the students, the performance of the students was average.

(b) In the second post-test, that is after the second iteration, where charts of periodic tables were prepared and given to the students in addition to the teaching and learning material used to teach them, the performance of the students was above average and

(c) In the third post-test, that is after the third iteration, where charts on how to assign oxidation numbers were also prepared and given to the students in addition to the periodic tables and the teaching and learning material used to teach them, the performance of the students was far above average.

(3) For changes in conceptions of both SHS 1A and SHS 2A students during the stages of teaching in the development of the teaching and learning material on the two topics, the study found that:

(a) From the pre-test to post-test 1, changes in students' alternative conceptions for the scientifically accepted conceptions were below average.

(b) From the post-test 1 to post-test 2, changes in students' alternative conceptions for the scientifically accepted conceptions was above average and

(c) From the post-test 2 to post-test 3, changes in students' alternative conceptions for the scientifically accepted conceptions was far above average.

(4) With regard to the performance of the validation SHS 1 students in the pre-test and post-tests during validation of the teaching and learning material already developed, the study found the following:

(a) The performance of the validation students in the pre-test before they were taught was poor.

(b) When the students were taught with the teaching and learning material already developed for four weeks, the performances of the students in the post-test was very good.

(5) For changes in the conceptions of the validation SHS 1 students during validation of the teaching and learning material already developed, the study found that from the pre-test to the post-test, changes in students' alternative conceptions for the scientifically accepted conceptions were far above average.

(6) Concerning the views of SHS chemistry teachers about issues bothering on the teaching and learning of chemical formulae and chemical equations at the SHS level, the teachers made the following clear:

(a) That the following ideas are central to writing of chemical formulae and chemical equations of inorganic compounds:

(i) chemical symbols of elements.

(ii) knowledge of atomic numbers of the elements.

(iii) the group and periods of the elements as well as their valencies or oxidation numbers.

(iv) electronic configuration of the elements

(v) the concept of electronegativity and electropositivity of elements

(vi) formulae of radicals or polyatomic ions and their valencies

(vii) the concept of reactivity of elements and radicals and how they interchange valencies

(viii) differences between empirical, molecular and structural formulae.

(b) That the difficulties/limitations connected with teaching chemical formulae of inorganic compounds were:

(i) Students inability to state the chemical symbols of the various elements or atoms

(ii) Students poor mastery of the rules for assigning oxidation numbers,

(iii) Students inability to remember the valencies of the various elements

(iv) Students difficulty understanding why there should be brackets in chemical formulae involving radicals or oxoanions.

(v) Scenarios or practical ways to help students understand the topic is a problem. Furthermore,

(vi) Non availability of concrete teaching and learning materials or non availability of models or software for e-learning of the topics makes it too abstract to students.

(vii) Poor presentation of the two topics in textbooks or lack of quality books of the topics is also a problem and many more.

(c) Concerning the difficulties/limitations students have with learning chemical formulae and chemical equations of inorganic compounds, the teachers provided the following information:

(i) Weak foundation from JHS

(ii) Students' inability to translate names of species especially radicals into formulae and difficulty in learning, remembering and applying the rules for naming inorganic compounds

(iii) Difficulty with the use of capital letters in writing chemical symbols.

(iv) Difficulty with assigning the elements to their groups and periods, assigning oxidation numbers to elements with variable oxidation states and difficulty writing the correct ionic form of the elements.

(v) Difficulty in predicting correct products of reactions

(vi) Difficulty in balancing chemical equations and many more.

(d) It was found that SHS chemistry teachers use the following teaching methods or strategies or procedures to help their students understand the two topics:

(i) helping students to assign and easily remember the rules for assigning oxidation numbers

(ii) solving more examples on oxidation numbers

(iii) helping students to identify and distinguish between ions, acids, bases, salts and binary compounds

(iv) thorough revision of chemical or atomic symbols

(v) demonstration with improvised models on the electronic arrangement in the atom

(vi) group work, problem-solving method, use of mnemonics to help students memorize chemical symbols, discussion method, dramatization and role play, demonstration using charts, diagrams and examples and many more.

(e) Concerning how SHS chemistry teachers ascertain students' understanding or confusion around the two topics, the following responses were prominent:

(i) calling students at random to answer questions in class,

(ii) looking at facial expression

(iii) from questions asked by students in class,

(iv) from the level of students concentration in class

(v) through feedback from class tests, class exercises, assignments and project works or group works.

(7) Results of all the hypotheses tested indicated that students' did better in terms of performance and changes in their conceptions when they were taught with the PCK material than when they were not taught with the PCK material.

Conclusions

The difficulty senior high school students have in the writing of chemical formulae and chemical equations as reported by WAEC chemistry Chief examiners included students inability to write correct formulae of compounds; inability to write the chemical equation for the reaction between Bronsted Lowry bases and concentrated acids like HCl; inability to write ionic equations; inability to write chemical equations of a simple reaction between sodium and water and inability to write a chemical equation to show that aluminium is amphoteric among many other wrong chemical equations written by students.

In a study conducted by Baah (2009), to investigate SHS 3 science students understanding of chemical formulae and chemical equations, it was found that SHS 3 science students have problem with the meaning of valencies of ions, problem with writing the correct formula of some radicals and some ions, difficulty in determining the number of atoms of each element in compounds and difficulty in determining the ions (cations and anions) that form ionic compounds. The findings by WAEC chemistry Chief examiners and the findings from the research conducted by Baah (2009) were confirmed by the preliminary findings of this study.

Studies conducted (Gower, 1977; Suderji, 1983 ; Savoy, 1988) have shown that the ability required to write chemical formulae and chemical equations correctly is not a simple one and that it is one that requires a functional understanding of the requisite subordinate concepts of atoms and atomicity, molecules and molecular formula, atomic structure and bonding, valency, use of brackets, radicals, subscripts, coefficient and molar ratio. The teaching and learning material developed in this study employed the concept of ionic bonding, valency, use of brackets, radicals and subscripts.

The teaching and learning material for chemical formulae and chemical equations developed in this study was developed along with lesson plans (see chapter three). The first three lessons were introduction to certain basic concepts needed by students and are therefore final products. Lessons four to six are the iterations through which the teaching and learning material was developed. The use of the teaching and learning material should therefore go hand in hand with the lesson plans.

The teaching and learning material developed in this study helped students in changing their alternative conceptions for the scientifically accepted conceptions as they were taken through different stages in it development. This was confirmed by the validation results.

Finally, the teaching and learning material developed in this study helped to improve the performance of the students as the mean vales all the post-tests in this study were significantly higher than their pre-test mean values.

Recommendations

The following recommendations are offered based on the findings of this study:

1. Based on key findings 2(b) chemistry teachers should always ensure that charts of the periodic table are always available to the students or in the classroom before they start to teach chemical formulae and chemical equations.
2. Based on key finding 2(c) chemistry teachers should teach oxidation numbers and how to assign them before they teach chemical formulae and chemical equations and not wait till SHS 3 when they are about to teach redox reactions.
3. Based on the outcome of the iterations, chemistry teachers should endeavour to teach and re-teach chemical formulae and chemical equations in the form of revision with varying examples as this strategy would help both the teacher and the students.
4. Chemistry teachers should endeavour to include illustrations and games in their lessons on how to write chemical formulae and chemical equations.

Suggestion for Future Research

The teaching and learning material developed in this study was used to teach the chemical formulae of inorganic compounds as well as the writing of combination, displacement and metathesis reactions because it was best suited for ionic species.

However, it did not look at how it could be used to teach the formulae of organic compounds and writing of the other types of chemical reactions: decomposition and combustion reactions. It is therefore recommended that future research is conducted to investigate this.

REFERENCES:

Abraham, M. R., & Renner, J. W. (1986). The sequence of learning cycle activities in high school chemistry. *Journal of Research in Science Teaching, 23*(2), 121-143.

Adams, P. E., & Krockover, G. H. (1997). Beginning science teacher cognition and its origin in the pre-service secondary science teacher program. *Journal of Research in Science Teaching, 34*(6), 633-653.

Alexander, P., & Murphy, P. (2000). The research base for APA's leaner-centered psychological principles. In N. Lambert, & B. McCombs (Eds.), *How students learn* (pp. 25-60). Washington DC, USA: American Psychological Association.

Ameyibor, K., & Wiredu, M. B. (1991). *Chemistry for senior secondary schools.* Accra: Unimax Macmillan.

Ampiah, J. G. (2004). *An investigation into science practical work in senior secondary schools: Attitudes and perceptions.* Unpublished PhD Thesis, University of Cape Coast, Cape Coast.

Anamuah-Mensah, J., & Apafo, N.T. (1986). Students perceived difficulties with ordinary level chemistry topics. *Chemistry and Industry Proceedings, 1*(1), 38-39.

Aronson, E., N., Blaney, C., Stephin, J., Sikes, M., & Snapp, J. (1992). *The jigsaw classroom*. Beverly Hills, CA: Sage Publishing Company.

Aronson, E., Blaney, N., Stephin, C., Sikes, J., & Snapp, M. (1978). *The jigsaw classroom*. Beverly Hills, CA: Sage Publishing Company.

Ary, D., Jacobs, L. C., & Razavieh, A. (1990). *Introduction to research in education* (4th ed.). New York: Holt, Rinehart and Winston, Inc.

Ausubel, D. P. (1968). *Educational psychology: A cognitive view*. New York: Holt Rinehart and Winston.

Baah, R. (2009). *Senior high school students understanding of chemical formulae and chemical equations.* Unpublished MPhil Thesis, University of Cape Coast, Cape Coast.

Babttista, M. T. (1999). The mathematical miseducation of America's youth. *Phi Delta Kappan, 80*(6), 424-433.

Bailey, K. D. (1994). *Methods of social research* (4th ed.). New York: The Free Press.

Ball, D., & McDiramid, G. (1990). The subject matter preparation of teachers. In W. Houston, M. Haberman & J. Sikula (Eds.), *Handbook of Research on Teacher Education* (pp. 437-449). New York: MacMillan.

Ball, D. L., & Cohen, D. K. (1996). Reform by the book: What is or might be the role of curriculum materials in teacher learning and instructional reform? *Educational Researcher, 25*(9), 6-8.

Ball, D. L. (2000). Bridging practices. *Journal of Teacher Education, 51*(3), 241-247

Banchi, H., & Bell, R. (2008). The many levels of inquiry. *Science and Children, 46*(2), 26-29.

Bandura, A. (1977). *Social learning theory.* New York: General Learning Press.

Barnea, N., & Dori, Y.J. (1996). Computerized molecular modeling as a tool to improve chemistry teaching. *Journal of Chemical Information and Computer Science, 36,* 629 - 636.

Barman, C. R. (1990). An expanded view of the learning cycle: New ideas about an effective teaching strategy. *The International Journal for Elementary Science, 4*(2), 208-212.

Baturo, A., & Nason, R. (1996). Student teachers' subject matter knowledge within the domain of area measurement. *Educcational Studies in Mathematics, 31*, 235-268.

Bello, O. O. (1988). An analysis of students' error in stoichiometric problems. *Nigerian Education Forum, 11*(2), 181- 186.

Bentley, M. L., Ebert, C., & Ebert, E. S. (2000). The learning cycle teaching approach. *Journal of Science Teacher Education, 3*(2), 58–64.

Bennett, B., Rolheiser, C., & Stevahn, L. (1991). *Cooperative learning: where heart meets mind.* Ontario: Book Press.

Ben-Zvi, R., Eylon, B., & Silberstein, J. (1986). Is an atom of copper malleable? *Journal of Chemical Education, 63*, 64 -66.

Ben-Zvi, R., Eylon, B., & Silberstein, J. (1987). Students' visualization of a chemical reaction. *Journal of Chemistry Education, 8*(4), 117 -120.

Ben-Zvi, R., Eylon, B., & Silberstein, J. (1988). Theories, principles and laws of chemical reactions. *Journal of Chemistry Education, 4*(2), 89 -92.

Blumberg, P. (2004). Beginning journey toward a culture of learner centered teaching. *Journal of Student Centered Learning, 2*(1), 68-80.

Bolling, A. (1994). Using group journals to improve writing and comprehension. *Journal of Excellent College Teaching, 5*(1), 47–55.

Borko, H., & Putnam, R. T. (1995). Expanding a teacher's knowledge base: A cognitive psychological perspective on professional development. In T. R. Guskey, & M. Huberman (Eds.), *Professional Development in Education: New Paradigms and Practices* (pp. 155-180) New York, NY: Teachers College Press.

Borko, H., & Putnam, R. (1996). Learning to teach. In D. Berliner, & R. Calfee (Eds), *Handbook of educational psychology* (pp. 673-708). New York: Macmillan.

Bowen, C. W. (2000). A quantitative literature review of cooperative learning effects on high school and college chemistry achievement. *Journal of Chemistry Education* 77(2), 116–119.

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings, *Journal of the Learning Sciences, 2,* 141-178.

Bruner, J. S. (1961). The act of discovery. *Harvard Educational Review 31*(1), 21–32.

Carpenter, T. P., Fennema, E., Peterson, P., & Carey, D. A. (1988). Teachers' pedagogical content knowledge of students' problem solving in elementary arithmetic. *Journal for Research in Mathematics Education, 19*(5), 385-401.

Carlsen, W. S. (1993). Teacher knowledge and discourse control: Quantitative evidence from new biology teachres' classroom. *Teaching & Teacher Education, 30*(5), 471-481.

Carter, K. (1993). The place of story in the study of teaching and teacher education. *Educational Researcher*, *22*, 5–12.

Clandinin, D. J., & Connelly, F. M. (1995). *Teachers' professional knowledge landscapes*. New York: Teachers College Press.

Clement, J. (1987). *The Use of Analogies and Anchoring Intuitions to Remediate Misconceptions in Mechanics*. Paper presented at the Annual Meeting of the American Educational Research Association (Washington, DC, April 20-24, 1987).

Cobern, W. W. (1996). Constructivism and non-western science education research. *International Journal of Science Education*, *4*(3), 287–302.

Cochran-Smith, M., & Lytle, S. L. (1990). Research on teaching and teacher research: The issues that divide. *Journal of Educational Research*, *19*(6), 2–10.

Collins, A. (1992). Towards a design of science of education. In E. Scanlon, & O'Shea, T. (Eds.), *New directions in educational technology* (pp.15-22). Berlin: Springer.

Colosi, J. C., & Zales, C. R. (1998). Jigsaw cooperative learning improves biology lab course. *Journal of Biological Science*, *48* (2), 118–124.

Coppola, B. P., Lawton, R. G. (1995). Who has the some substance that I have? A blueprint for collaborative learning activities. *Journal of Chemistry Education*, *72* (12), 1120-1122.

Copolo, C. F., & Hounshell, P. B. (1995). Using three-dimensional models to teach molecular structures in high school chemistry. *Journal of Science Education and Technology, 4*(4), 295 -305.

Creswell, J.W., & Plano Clark, V.I. (2011). *Designing and conducting mixed methods research* (2nd ed.). Los Angeles: Sage.

Davis, E. A., & Krajcik, J. (2005). Designing educative curriculum materials to promote teacher learning. *Educational Researcher, 34*(3), 3-14.

Driver, R., & Oldham, V. (1986). A constructivist approach to curriculum development in science. *Journal of Studies in Education, 13*(4), 105–122.

Eilks, I. (2005). Experiences and reflections about teaching atomic structure in a jigsaw classroom in lower secondary school chemistry lessons. *Journal of Chemistry Education, 82*(2), 313–319.

Eisenhart, M., Borko, H., Underhill, R., Brown, C., Jones, D., & Agard, P. C. (1993). Conceptual knowledge falls through the cracks: complexities of learning to teach mathematics for understanding. *Journal for Research in Mathematics Education, 24*(1), 8-40.

Elliott, J., (1991). *Action research for educational change*. London, England: Open University Press.

Even, R. (1993). Subject-matter knowledge and pedagogical content knowledge: prospective secondary teachers and the function concept. *Journal for Research in Mathematics Education, 24*(2), 94-116.

Feiman-Nemser, S., & Buchmann, M. (1985). The First Year of Teacher Preparation: Transition of Pedagogical Thinking? *Journal of Research in Education, 156*(10), 88-104.

Feiman-Nemser, S., & Floden, R. (1986). The cultures of teaching. In M.C. Wittrock (Ed.), *Handbook of research on teaching* (pp. 505–526). New York: Macmillan.

Fraenkel, J. R., Wallen, N. E., & Hyun, H. (2012). *How to design and evaluate research in education.* New York: McGraw-Hill.

Gabel, D., & Sherwood, R. (1980). The effect of student manipulation of molecular models on chemistry achievement according to Piagetian level. *Journal of Research in Science Teaching, 17*(1), 75-81.

Gabel, D. (1998). The complexity of chemistry and implications for teaching. In B. J. Fraser, & K. G. Tobin, (Eds.), *International handbook of science education* (pp. 233 - 248). Boston, MA: Kluwer Academic Publishers

Gabel, D. L., Samuel, K. V., & Hunn, D. (1987). Understanding the particulate nature ofmatter. *Journal of Chemical Education, 64,* 695-697.

Gardener, B. S., & Korth, S. D. (1996). Using reflection in cooperative learning groups to integrate theory and practice. *Journal of Excellent College Teaching, 7*(1), 17–30.

Garmston, G. J. (1996). Adult learners, instruments and the "big C". *Journal of Staff Development, 17* (3), 53-54.

Geddis, A. N., Onslow, B., Beynon, C., & Oesch, J. (1993). Transforming content knowledge: Learning to teach about isotope. *Science Education, 77*(6), 575-591.

Gess-Newsome, J. (1999). Secondary teachers' knowledge and beliefs about subject matter and their impact on instruction. In J. Gess-Newsome, & N. G. Lederman (Eds.), *Examining Pedagogical Content Knowledge* (pp. 51-94). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Gess-Newsome, J., & Lederman, N. (Eds). (1999). *Examining pedagogical content knowledge*. Dordrecht, The Netherlands: Kluwer.

Gillies, R. M. (2006). Teachers' and students' verbal behaviors during cooperative and small-group learning. *British Journal of Educational Psychology, 76*(2), 271–287.

Goodlad, J. L. (1984). *A place called school. Prospects for the future*. New York, NY: McGraw Hill Book Company.

Gower, D. M., Daniels, D. J. & Lioyd, G. (1977). Hierarchies among the concepts which underlie the mole. *School Science Review*, *59* (201), 285-297.

Graham, D. C. (2005). *Cooperative learning methods and middle school students.* Unpublished PhD Thesis, Capella University, Minneapolis, USA.

Gray, D. E. (2009). *Doing research in the real world.* Los Angeles: SAGE.

Greeno, J. G., Collins, A., & Resnick, L. (1996). Cognition and learning. In D. C. Berliner, and R. C. Calfee, (Eds.), *Handbook of educational psychology* (pp. 15-46), New York: Macmillan.

Grimmet, P., & MacKinnon, A. (1992). Craft knowledge and the education of teachers. In G. Grant (Ed.), *Review of research in education* (pp. 59-74). Washington, DC: AERA.

Grossman, P. L., Wilson, S. M., & Shulman, L. S. (1989). Teachers of substance: Subject matter knowledge for teaching. In M. Reynolds (Ed.), *Knowledge base for the beginning teacher*. New York: Pergamon.

Grossman, P. L. (1990). *The Making of Teacher: Teacher knowledge and teacher education*. New York: Teachers College Press.

Grossman, P. L. (1990). *The making of a teacher: Teacher knowledge and teacher education*. New York: Teachers College Press.

Hashweh, M. Z. (1985). *An exploratory study of teacher knowledge and teaching : the effects of science teachers' knowledge of subject-matter and their conceptions of learning on their teaching*. Stanford, CA: Stanford University.

Heaton, R. M. (2000). *Teaching mathematics to the new standards: Relearning the dance*. New York: Teachers College Press.

Hennessy, D., & Evans, R. (2006). Small-group learning in the community college classroom. *Community College Classroom, 12*(1), 93–109.

Henson, K. T. (2003). Foundations for learner-centered education: A knowledge base. *Education, 124* (1), 5-16.

Hewson, P. W. (1992). *Conceptual change in science teaching and teacher education*. A paper presented at a meeting on "Research and Curriculum Development in Science Teaching," under the auspices of the National Centre for Educational Research, Documentation and Assessment, Ministry of Education and Science, Madrid, Spain, June, 1992.

Hewson, P., & Hewson, M. (1992). The status of students' conceptions. In R. Duit, F. Goldberg, & A. Niedderer (Eds.), *Research in Physics Learning: Theoretical Issues and Empirical Studies* (pp. 59-73). Kiel: IPN – Leibniz Institute for Science Education.

Hines, C. (1990). Students' understanding of chemical equations in secondary schools in Botswana. *School Science Review*, *72*(285), 138-140.

Hoffmann, R., & Laszlo, R. (1991). Representation in chemistry. *Angewandte Chemie, 30,* 1-16.

Hollingsworth, S. (1997). *International action research: A casebook for educational reform.* London: Falmer Press.

Hooper, S., & Hannafin, M. J. (1988). Cooperative CBI: The effects of heterogeneous versus homogeneous grouping on the learning of progressively complex concepts. *Journal of Educational Computing Research, 14(9),* 413-424.

Hooper, S., Ward, T. J., Hannafin, M. J., & Clark, H. T. (1989). The effects of aptitude comprehension on achievement during small group learning. *Journal of Computer Based Instruction, 16(10),* 102-109.

Huang, H. M. (2002). Toward constructivism for adult learners in online learning environments. *British Journal of Educational Technology, 33*(1), 27-37.

Johnstone, A. H., Morrison, T. I., & Sharp, D.W.A. (1976). Topic difficulties in chemistry. *Education in Chemistry, 20*, 212-218.

Johnstone, A. H. (1974). Evaluation of chemistry syllabuses in Scotland. *Studies in Science Education, 1*, 20-49.

Johnson, D. W., Johnson, R. T., & Smith, K. A. (1991). *Active learning: Cooperation in the college classroom.* Edina, MN: Interaction Book Company.

Jonassen, D. H. (1994). Thinking technology: Towards a constructivist design model. *Educational Technology, 34*(4), 34–47.

Jones, L. L., Buckler, H., Cooper, N., & Straushein, B. (1997). Preparing preservice chemistry teachers for constructivist classrooms through use of authentic activities. *Journal of Chemical Education,* 14(7), 787-790.

Johnson, D. W., & Johnson, R. T. (1999). What makes cooperative learning work. In D. Kluge, S. McGuire, D. W. Johnson, & R. T. Johnson (Eds.), *Cooperative learning* (PP. 82-95). Tokyo: Japan Association for Language Teaching.

Kesidou, S., & Roseman, J. E. (2002). How well do middle school science programs measure up? Findings from Project 2061's curriculum review. *Journal of Research in Science Teaching, 39*(6), 522-549.

Kitta, S. (2004). *Enhancing mathematics teachers' pedagogical content knowledge and skills in Tanzania.* Enschede: University of Twente.

Kozma, R. B., Russell, J., Jones, T., Marx, N., & Davis, J. (1996). *The use of multiple, linked representations to facilitate science understanding.* In R. G. Vosniadou, S. E. DeCorte & H. Mandel (Eds.), *International perspective on the psychological foundations of technology-based learning environments* (pp. 41- 60). Hillsdale, NJ: Erlbaum.

Krajcik, J. S. (1991). Developing students' understanding of chemical concepts. In S. M. Glynn, R. H. Yeany, & B. K. Britton (Eds.), *The psychology of learning science: International perspective on the psychological foundations of technology-based learning environments* (pp. 117-145). Hillsdale, NJ: Erlbaum.

Krajcik, J., Blumenfeld, P., Marx, R., & Soloway, E. (2000). Instructional, curricular, and technological supports for inquiry in science classrooms. In J. Minstrell, & E. Van Zee (Eds.), *Inquiring into inquiry learning and teaching in science* (pp. 283-315). Washington, DC: American Association for the Advancement of Science.

Krajcik, J., Mamlok, R., & Hug, B. (2001). Modern content and the enterprise of science: Science education in the twentieth century. In L. Corno (Ed.), *Education across a century: The centennial volume* (pp. 205-231). Chicago: NSSE.

Küçüközer, H., & Kocakülah, S. (2008). Effect of simple electric circuits teaching on conceptual change in grade 9 physics course. *Journal of Turkish Science Education, 5* (1), 59-74.

Lambert, N., & McCombs, B. (2000). Introduction: Learner-centered schools and classrooms as a direction for school reform. In N. Lambert, & B. McCombs (Eds.), *How students learn* (pp. 1-15). Washington, D.C.: American Psychological Association.

Lave, J., & Wenger, E. (1990). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.

Lave, J., & Wenger, E. (1991). *Situated Learning.* New York: Cambridge press.

Lawson, A. E., Abraham, M. R., & Renner, J. W. (1989). *A theory of instruction: Using the learning cycle to teach science concepts and thinking skills [Monograph, Number One].* Manhattan: National Association for Research in Science Teaching.

Lazonby, J. N., Morris, J. E., & Waddington, D. J. (1982). The muddle some mole. *Education in Chemistry, 19*, 109-111.

Levine, E. (2001). Reading your way to scientific literacy. *Journal of College Science Teaching, 31*(2), 122–125.

Lin, E. (2006). Learning in the science classroom. *Journal of Science Teaching, 73*(5), 35–39.

Ma, L. (1999). *Knowing and teaching elementary mathematics*. Mahwah, NJ: Lawrence Erlbaum Associates.

Mafumiko, F. (2006). *Micro-scale experimentation as catalyst for improving the chemistry curriculum in Tanzania*. Enschede: University of Twente.

Magnusson, S., Krajcik, J. S., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome, & N. G. Lederman (Eds.), *Examining Pedagogical Content Knowledge, the construct and its implications for science education* (pp. 95-132). Boston: Kluwer Academic Publishers.

Maloof, J., & White, V. K. B. (2005). Team study training in the college biology laboratory. *Journal of Biology Education, 39*(3), 120-124.

Mansfield, H., & Happs, J. (1996). Using student conception of parallel lines to plan a teaching program. In D. F. Treagust, R. Duit, & B. J. Fraser (Eds.), *Improving teaching and learning science and mathematics* (pp. 65-98). New York: Teacher College Press.

Mathews, R. S., Cooper, J. L., Davidson, N., & Hawkes, P. (1995). Build bridges between cooperative and collaborative learning. *Change, 4,* 35-40.

Marks, R. (1990). Pedagogical content knowledge: From a mathematical case to a modified conception. *Journal of Teacher Education, 41*(3), 3-11.

Matlin, M. W. (2002). Cognitive psychology and college-level pedagogy: Two siblings that rarely communicate. In D. F. Halpern, & M. D. Hakel (Eds.), *Applying the science of learning to university teaching and beyond.* (pp. 87-103). San Francisco: Jossey-Bass.

Mckenney, S. (2001). *Computer-based support for science education materials developers in Africa: Exploring potentials*. Enschede: University of Twente.

McLellan, H. (1996). *Situated learning perspectives*. Englewood Cliffs: Educational Technology Publications.

Mergendoller, J., & Packer, M. J. (1989). *Cooperative learning in the classroom: A knowledge brief on effective teaching.* San Francisco: Far West Laboratory.

Merriam, S. B., Caffarella, R. S., & Baumgartner, L. M. (2007). *Learning in adulthood: A Comprehensive guide*. San Francisco, CA: Jossey-Bass.

Miller, A. K. (1989). Enhanchmg early chılhood mamstreammg through Cooperatıve Leamıng: A Brief Lıterature Revıew. *Journal of Children Studies, 19*(4), 285-291.

Miller, L., & Silvernail, D. L. (1994). Wells Junior High School: Evolution of a professional development school. In L. Darling-Hammond (Ed.), *Professional development schools: Schools for developing a profession* (pp. 56-80). New York: Teachers College Press.

Morine-Dershimer, G., & Kent, T. (1999). The complex nature and sources of teachers' pedagogical knowledge. In J. Gess-Newsome, & N. G. Lederman (Eds.), *Examining Pedagogical Content Knowledge* (pp. 301-331). Norwell: Kluwer Academic Publishers.

Nastasi, B. K., & Clements, D. H. (1991). Research on cooperative learning: implications for practice. *School Psychology Review, 20,* 110-131.

Needham, R. A., Powell, D., & Bentley, M. L. (1994). *Using big books in science and social studies.* A paper presented at the annual meeting of International Reading Association, Toronto, Canada.

Novak, J. (1993). Human constructivism: A unification of psychological phenomena in meaning making. *International Journal of Personal Construct Psychology, 6,* 167–193.

Nussbaum, J., & Novick, S. (1982). Alternative framework, conceptual conflict and accommodation: toward a principled teaching strategy. *Instructional Science*, *11*, 183-200.

Odom, A. L., & Kelly, P. V. (2001). Integrating concept mapping and learning cycle to teach diffusion and osmosis concepts to high school biology students. *Science Education, 85*, 615–635.

Ornstein, A. C., Thomas, J., & Lasley, I. (2000). *Strategies for effective teaching*. New York: McGraw-Hill.

Ottevanger, W. (2001). *Teacher support materials as catalyst for science curriculum implementation in Namibia*. Enschede: University of Twente.

Parker, R. (1985). Small-group cooperative learning in the classroom. *Oregon School Study Council Bull, 27*(7), 1–28.

Piaget, J. (1952). *Child's conception of number*. London: Routledge and Kegan Paul.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66* (2), 211 – 227

Postman, A., Neil, G., Weingartner, T., & Charles, W. (1969), *Teaching as a Subversive Activity*. New York, NY: Dell

Prichard, J. S., Bizo, L. A., Stratford, R. J. (2006). The educational impact of team-skills training: Preparing students to work in groups. British Journal of Educational Psychology, *76*(1), 119–140.

Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education, 93*(3), 223–231.

Proulx, J. (2006). Constructivism: A re-equilibration and clarification of the concepts, and some potential implications for teaching and pedagogy. *Radical Pedagogy, 8* (1), 64-89.

Richey, R. C. & Nelson, W. A. (1996). Developmental research. In D. Jonassen (Ed.), *Handbook of research for educational communications and technology* (pp. 1213-1245). London : Macmillan.

Reigeluth, C. M., & Frick, W. (1999). Formative research: A methodology for creating and improving design theories, In C. Reigeluth (Ed.), *Instructional-design theories and models. A new paradigm of instructional theory* (pp. 633-651). New Jersey: Lawrence Erlbaum Associates.

Remillard, J. T. (2000). Can curriculum materials support teachers' learning? Two fourth-grade teachers' use of a new mathematics text. *The Elementary School Journal, 100*(4), 331-350.

Renner, J. M., Abraham, M. R., & Birnie, H. H. (1986). The occurrence of assimilation and accommodation in learning high school physics. *Journal of Research in Science Teaching, 23* (7), 619-634.

Savoy, L. G. (1988). Balancing chemical equations. *School Science Review, 249* (69), 713-720.

Scott, P. H., Asoko, H. M., & Driver, R. H. (1992). Teaching for conceptual change: Areview of strategies. In R. Duit, F. Goldberg, & A. Niedderer (Eds.), *Research in Physics Learning: Theoretical Issues and Empirical Studies* (pp.310-329). Kiel: IPN–Leibniz Institute for Science Education.

Schneider, R., & Krajcik, J. (2002). Supporting science teacher learning: The role of educative curriculum materials. *Journal of Science Teacher Education, 13*(3), 221-245.

Schneider, R., Krajcik, J., & Blumenfeld, P. (2005). Enacting reform-based science materials: The range of teacher enactments in reform classrooms. *Journal of Research in Science Teaching, 42*(3), 283-312.

Schneider, R. (2006). Supporting science teacher thinking through curriculum materials. In S. A. Barab, K. E. Hay, & D. T. Hickey (Eds.), *Proceeding of the seventh international conference the learning of sciences,* (pp. 674-680). Mahwah: Lawrence Erlbaum Associates.

Siegel, C. (2005). Implementing a research-based model of cooperative learning. *Journal of Educational Research, 98*(6), 339-350.

Shulman, L. S. (1986). Paradigms and research programs for the study of teaching. In M.C. Wittrock (Ed.), *Handbook of Research on Teaching* New York: Macmillan.

Shulman, L. S. (1986). Those who understand: knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1-22.

Shulman, L. (1992). Ways of seeing, ways of knowing, ways of teaching, ways of learning about teaching. *Journal of Curriculum Studies, 28*, 393-396.

Slavin, R. E., & Sharan, S. (1990). *Comprehensive cooperative learning methods: embedding cooperative learning in the curriculum and school, cooperative learning: theory and research.* New York: Preston Press.

Slavin, R. E., Madden, N. A., Karweit, N., Livermon, B. J., & Dolan, L. (1995). Success for all: First year outcomes of a comprehensive plan for reforming urban education. *Journal of American Education, 27*, 255-278.

Spigner-Littles, D., & Anderson, C. E. (1999). Constructivism: A paradigm for older learners. *Educational Gerontology, 25* (3), 203-209.

Springer, L., Stanne, M., & Donovan, S. (1999). Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology (health sciences): A meta-analysis. *Review of Educational Research, 69*(1), 21–51.

Stake, R. E., & Easley, J. A. (1978). *Case studies in science education* (Vol. 2). Washington: Government Printing Office.

Sternberg, R. J., & Grigorenko, E. L. (2002). The theory of successful intelligence as a basis for instruction and assessment in higher education. In D. F. Halpern, & M. D. Hakel (Eds.), *Applying the science of learning to university teaching and beyond* (pp. 45-54). San Francisco: Jossey-Bass.

Stohl-Drier, H. (2001). Teaching and learning mathematics with interactive spreadsheets. *School Science and Mathematics, 101*(4), 170-179.

Stronkhost, R. (2001). *Improving science education in Swaziland: The role of in-service education.* Enschede: University of Twente.

Suderji, B. (1983). Chemical equations conquered. *School Science Review, 65* 101-102.

Talbert, J. E., & McLaughlin, M. W. (1993). Understanding teaching in context. In D. Cohen (Ed.), *Teaching for understanding: Challenges for policy and practice* (458-560). San Francisco, CA: Jossey-Bass Inc.

Tilya, F. N. (2003). *Teacher support for the use of MBL in activity-based physics teaching in Tanzania*. Enschede: University of Twente.

Thijs, A. (1999). *Supporting science curriculum reform in Botswana: The potential of peer coaching*. Enschede: University of Twente.

Trochim, W. (2000). *The Research Methods Knowledge Base* (2nd ed.). Cincinnati, OH: Atomic Dog Publishing.

Trowbridge, L. W., Bybee, R. W., & Powell, J. C. (2004). *Teaching secondary school science*. Upper Saddle River: Prentice Hall

Türkmen, H. (2006). How should science be taught by using learning cycle approach in elementary schools? *Elementary Education Online*, *5* (2), 1-15. [Retrieved August 26, 2006 from http://eric.ed.gov]

Van den Akker, J., & Plomp, T. (1993). *Development research in curriculum: Propositions and experiences*. A paper presented at AERA meeting. April 12 – 16, Atlanta, GA

Van den Akker, J. (1999). Principles and methods of development research. In J. van den Akker, R. Branch, K. Gustafson, N. Nieveen, & T. Plomp, (Eds.). *Design Approaches and Tools in Education and Training* (pp. 1-14). Dordrecht: Kluwer Academic Publishers.

Van den Akker, J. (2002). The added value of development research for educational development in developing countries. In K. Osaki, W.

Ottevanger, C. Uiso, & J. van den Akker (Eds.). *Science Education Research and Teacher Development in Tanzania* (pp. 51- 67). Amsterdam: Vrije Universiteit.

Van Driel, J. H., Verloop, N., & de Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching, 35*(6), 673–695.

Van den Akker, J., & Plomp, T. (1993). *Development research in curriculum: Propositions and experiences.* Paper presented at AERA meeting, April 12-16, Atlanta.

Vosniadou, S. (1994). Capturing and modeling the process of conceptual change. *Journal of Learning and Instruction, 4*, 45-69.

Vygotsky, L. S. (1978). *Mind in society.* Cambridge, MA: Harvard University Press.

Webb, N., & Cullian, L. K. (1983). Group interaction and achievement in small groups: suitability over time. *American Educational Research Journal, 20(3),* 389-397.

Webb, N. (1992). Testing a theoretical model of student interaction and learning in small groups. In R. Hertz-Lazarowitz Miller (Eds.). *Introduction in Cooperative Groups: the Theoretical Anatomy of Group Learning.* (pp. 102-119). New York: Cambridge University Press.

Webb, N. M., Sydney, H., & Farivor, A. M. (2002). Theory into practice. *Journal of College Education, 41*(1), 13-20.

Weimer, M. (2002). *Learner-centered teaching*. San Francisco: Jossey-Bass.

Welch, W. W. (1979). Twenty years of science curriculum development: A look back. *Review of Research in Education, 7*, 282-308.

West African Examinations Council. (1994). *Chief Examiners' Report*, SSSCE. Accra: Wisdom Press.

West African Examinations Council. (1995). *Chief Examiners' Report*, SSSCE. Accra: Wisdom Press.

West African Examinations Council. (1999). *Chief Examiners' Report*, SSSCE. Accra: Wisdom Press.

West African Examinations Council. (2001). *Chief Examiners' Report*, SSSCE (private). Accra: Wisdom Press.

West African Examinations Council. (2003). *Chief Examiners' Report*, SSSCE. Accra: Wisdom Press.

West African Examinations Council. (2004). *Chief Examiners' Report*, SSSCE. Accra: Wisdom Press.

West African Examinations Council. (2005). *Chief Examiners' Report*, SSSCE. Accra: Wisdom Press.

West African Examinations Council. (2008). *Chief Examiners' Report*, SSSCE. Accra: Wisdom Press.

West African Examinations Council. (2009). *Chief Examiners' Report*, SSSCE. Accra: Wisdom Press.

West African Examinations Council. (2013). *Chief Examiners' Report*, SSSCE. Accra: Wisdom Press.

Wheatley, G. H. (1991). Constructivist perspectives on science and mathematics learning. *Science Education*, *75* (1), 9-21.

White, R. T., & Gunstone, R. F. (1992). *Probing understanding*. Great Britain: Falmer Press.

Wilson, S. M., Shulman, L. S., & Richert, A. E. (1987). '150 Different ways' of knowing: representations of knowledge in teaching. In J. Calderhead (Ed.), *Exploring Teachers' Thinking*. (pp. 155-301). Salisbury, Wiltshire: Cassell Educational Limited.

APPENDICES:

APPENDIX A

PRE-TEST

TEST ON WRITING OF CHEMICAL FORMULAE

SCHOOL: SEX : AGE :

INSTRUCTION : Answer all questions

For **each** compound below:

(a) Write the **formula** of the compound

(b) Write the **constituent ions** that formed the compound

(c) What are the **subscripts of these ions** in the formula if they have any?

(d) What do those **subscripts mean** for the ions if they have any?

(e) What is the **valency** of each constituent ion

1. Iron (III) trixoxocarbonate (IV)
2. Silver nitride
3. Iron (III) tetraoxosulphate (VI)
4. Ammonium trioxocarbonate (IV)
5. Lithium trioxocarbonate (IV)
6. Aluminium tetraoxosulphate (VI)
7. Copper (II) tetraoxophosphate (V)
8. Calcium tetraoxophosphate (V)
9. Ammonium sulphide

APPENDIX B

PRE-TEST

TEST ON WRITING OF CHEMICAL EQUATIONS

SCHOOL : AGE : SEX :

INSTRUCTION : Answer all questions

Translate the following statement reactions into balanced chemical equations in symbols

1. Aluminium metal ion reacts with fluoride ion to form aluminium fluoride
2. Iron (II) metal ion reacts with fluoride ion to form iron (II) fluoride
3. Potassium hydroxide reacts with tetraoxophosphate (V) acid to form potassium tetraoxophosphate (V) and water
4. Sodium oxide reacts with trioxonitrate (V) acid to form sodium trioxonitrate (V) and Water
5. Copper (II) metal reacts with silver trioxonitrate (V) to form copper (II) trioxonitrate (V) and silver metal
6. Potassium tetraoxochromate (VI) reacts with lead trioxonitrate (V) to form lead tetraoxochromate (VII) and potassium trioxonitrate (V)

APPENDIX C

POST-TEST 1

TEST ON WRITING OF CHEMICAL FORMULAE

INSTRUCTION : Answer all questions

For **each** compound below:

(a) Write the **formula** of the compound

(b) Write the **constituent ions** that formed the compound

(c) What are the **subscripts of these ions** in the formula if they have any?

(d) What do those **subscripts mean** for the ions if they have any?

(e) What is the **valency** of each constituent ion

1. Potassium tetraoxochromate (VI)
2. Copper (II) trioxonitrate (V)
3. Iron (II) nitride
4. Calcium heptaoxodichromate (VI)
5. Lithium trioxochlorate (V)
6. Barium tetraoxomanganate (VII)
7. Aluminium sulphide
8. Mercury (I) oxide
9. Beryllium hydroxide

APPENDIX D

POST-TEST 1

TEST ON WRITING OF CHEMICAL EQUATIONS

INSTRUCTION : Answer all questions

Translate the following statement reactions into balanced chemical equations in symbols

1. Silver metal ion reacts with nitride ion to form Silver nitride
2. Zinc metal ion reacts with sulphide ion to form Zinc sulphide
3. Calcium hydroxide reacts with trioxonitrate (V) acid to form Calcium trioxonitrate (V) and water
4. Aluminium oxide reacts with hydrochloric acid to form Aluminium chloride and water
5. Magnesium metal ion reacts with tetraoxosulphate (VI) acid to form Magnesium tetraoxosulphate (VI) and hydrogen gas
6. Barium metal ion reacts with trioxocarbonate (IV) acid to form Barium trioxocarbonate (IV) and hydrogen gas

APPENDIX E

POST-TEST 2

TEST ON WRITING OF CHEMICAL FORMULAE

INSTRUCTION : Answer all questions

For **each** compound below:

(a) Write the **formula** of the compound

(b) Write the **constituent ions** that formed the compound

(c) What are the **subscripts of these ions** in the formula if they have any?

(d) What do those **subscripts mean** for the ions if they have any?

(e) What is the **valency** of each constituent ion

1. Silver oxide
2. Aluminium trioxosulphate (IV)
3. Ammonium trioxocarbonate (IV)
4. Zinc bromide
5. Barium tetraoxophosphate (V)
6. Copper (II) trioxosulphate (IV)
7. Iron (II) oxide
8. Sodium trioxonitrate (V)
9. Lead (II) tetraoxosulphate (VI)

APPENDIX F

POST-TEST 2

TEST ON WRITING OF CHEMICAL EQUATIONS

INSTRUCTION : Answer all questions

Translate the following statement reactions into balanced chemical equations in symbols

1. Potassium metal ion reacts with bromide ion to form Potassium bromide
2. Beryllium metal ion reacts with iodide ion to form Beryllium iodide
3. Magnesium oxide reacts with tetraoxophosphate (V) acid to form Magnesium tetraoxophosphate (V) and water
4. Lithium hydroxide reacts with trioxosulphate (IV) acid to form Lithium trioxosulphate (IV) and water
5. Zinc metal ion reacts with silver trioxonitrate (V) to form Zinc trioxonitrate (V) and silver metal
6. Iron (II) metal ion reacts with Copper (II) tetraoxosulphate (VI) to form Iron (II) tetraoxosulphate (VI) and copper metal

APPENDIX G

POST-TEST 3

TEST ON WRITING OF CHEMICAL FORMULAE

INSTRUCTION : Answer all questions

For **each** compound below:

(a) Write the **formula** of the compound

(b) Write the **constituent ions** that formed the compound

(c) What are the **subscripts of these ions** in the formula if they have any?

(d) What do those **subscripts mean** for the ions if they have any?

(e) What is the **valency** of each constituent ion

1. Lithium nitride
2. Iron (III) sulphide
3. Lead (II) trioxocarbonate (IV)
4. Ammonium tetraoxosulphate (VI)
5. Sodium trioxochlorate (V)
6. Copper (II) fluoride
7. Beryllium hydroxide
8. Iron (II) cyanide
9. Zinc trioxocarbonate (IV)

APPENDIX H

POST-TEST 3

TEST ON WRITING OF CHEMICAL EQUATIONS

INSTRUCTION : Answer all questions

Translate the following statement reactions into balanced chemical equations in symbols

1. Copper (II) metal ion reacts with tetraoxosulphate (VI) ion to form Copper (II) tetraoxosulphate (VI)
2. Barium metal ion reacts with hydroxide ion to form Barium hydroxide
3. Potassium hydroxide reacts with trioxonitrate (V) acid to form Potassium trioxonitrate (V) and water
4. Calcium oxide reacts with tetraoxosulphate (VI) acid to form Calcium tetraoxosulphate (VI) and water
5. Sodium metal ion reacts with Aluminium trioxonitrate (V) to form Sodium trioxonitrate (V) and aluminium metal
6. Calcium metal ion reacts with Lead (II) tetraoxosulphate (VI) to form Calcium tetraoxosulphate (VI) and lead metal

APPENDIX I

VALIDATION PRE-TEST

TEST ON WRITING OF CHEMICAL FORMULAE

SCHOOL: SEX : AGE :

INSTRUCTION : Answer all questions

For **each** compound below:

(a) Write the **formula** of the compound

(b) Write the **constituent ions** that formed the compound

(c) What are the **subscripts of these ions** in the formula if they have any?

(d) What do those **subscripts mean** for the ions if they have any?

(e) What is the **valency** of each constituent ion

1. Iron(III) trixoxocarbonate (IV)
2. Silver nitride
3. Iron (III) tetraoxosulphate (VI)
4. Ammonium trioxocarbonate (IV)
5. Lithium trioxocarbonate (IV)
6. Aluminium tetraoxosulphate (VI)
7. Copper (II) tetraoxophosphate (V)
8. Calcium tetraoxophosphate (V)
9. Ammonium sulphide

APPENDIX J

VALIDATION PRE-TEST

TEST ON WRITING OF CHEMICAL EQUATIONS

SCHOOL : AGE : SEX :

INSTRUCTION : Answer all questions

Translate the following statement reactions into balanced chemical equations in symbols

1. Aluminium metal ion reacts with fluoride ion to form aluminium fluoride
2. Iron (II) metal ion reacts with fluoride ion to form iron (II) fluoride
3. Potassium hydroxide reacts with tetraoxophosphate (V) acid to form potassium tetraoxophosphate (V) and water
4. Sodium oxide reacts with trioxonitrate (V) acid to form sodium trioxonitrate (V) and Water
5. Copper (II) metal reacts with silver trioxonitrate (V) to form copper (II) trioxonitrate (V) and silver metal
6. Potassium tetraoxochromate (VI) reacts with lead trioxonitrate (V) to form lead tetraoxochromate (VII) and potassium trioxonitrate (V)

APPENDIX K

VALIDATION POST-TEST

TEST ON WRITING OF CHEMICAL FORMULAE

INSTRUCTION : Answer all questions

For **each** compound below:

(a) Write the **formula** of the compound

(b) Write the **constituent ions** that formed the compound

(c) What are the **subscripts of these ions** in the formula if they have any?

(d) What do those **subscripts mean** for the ions if they have any?

(e) What is the **valency** of each constituent ion

1. Calcium hydrogen trioxosulphate (IV)
2. Barium tetraoxomanganate (VII)
3. Sodium tetraoxophosphate (V)
4. Lithium hydrogen tetraoxosulphate (VI)
5. Copper (I) nitride
6. Aluminium chloride
7. Ammonium trioxocarbonate (IV)
8. Potassium heptaoxodichromate (VI)
9. Silver sulphide

APPENDIX L

VALIDATION POST-TEST

TEST ON WRITING OF CHEMICAL EQUATIONS

INSTRUCTION : Answer all questions

Translate the following statement reactions into balanced chemical equations in symbols

1. Iron (III) metal ion reacts with trioxocarbonate (IV) ion to form Iron (III) trioxocarbonate (IV)
2. Mercury (I) ion reacts with oxide ion to form Mercury (I) oxide
3. Iron (III) oxide reacts with trioxocarbonate (IV) acid to form Iron (III) trioxocarbonate (IV) and water
4. Lithium hydroxide reacts with tetraoxophosphate (V) acid to form Lithium tetraoxophosphate (V) and water
5. Sodium metal ion reacts with Aluminium trioxonitrate (V) to form Sodium trioxonitrate (V) and aluminium metal
6. Aluminium metal ion reacts with Lead (II) tetraoxosulphate (VI) to form Aluminium tetraoxosulphate (VI) and lead metal

APPENDIX M

CHI-SQURE DISTRIBUTION TABLE

	Probability of the Chi-Square [P (χ^2)]							
df	0.995	0.975	0.9	0.5	0.1	0.05	0.05	0.01
1	0.000	0.000	0.016	0.455	2.706	3.841	5.024	6.635
2	0.010	0.051	0.211	1.386	4.605	5.991	7.378	9.210
3	0.072	0.216	0.584	2.366	6.251	7.815	9.348	11.345
4	0.207	0.484	1.064	3.357	7.779	9.488	11.143	13.277
5	0.412	0.831	1.610	4.351	0.236	11.070	12.832	15.086
6	0.676	1.237	2.402	5.348	10.645	12.592	14.449	16.812
7	0.989	1.690	2.833	6.346	12.017	14.067	16.013	18.475
8	1.344	2.180	3.490	7.344	13.362	15.507	17.535	20.090
9	1.735	2.700	4.168	8.343	14.684	16.919	19.023	21.666
10	2.156	3.247	4.865	9.342	15.987	18.307	20.483	23.209

APPENDIX N

DESCRIPTION OF MCNEMAR CHI-SQUARE

Changes in students' conceptions in hypotheses 1, 2, 3, 4, 5 and 6 were analysed using the McNemar chi square test for significance of change. McNemar Chi-Square test for significance of change was used because it has the ability to determine the degree of changes in students' conceptions from the pre-test to the post-tests. To determine the degree of change in students' conceptions from the pre-test to the post-tests, the McNemar chi square test for significance of changes was used. To do this, a fourfold table of frequencies was set up to represent the pre-test and post-tests responses from the students. The features of the table are illustrated in Figure 3, in which positive (+) and negative (–) signs are used to signify the different responses given by students.

		After -	After +
Before	+	A	B
	-	C	D

Figure 3: Fourfold table used in testing significance of change

The – sign means presence of alternative conception before or after intervention and the + sign means there is no alternative conception before or after intervention. A student is tailed in cell 'A' if there is a change in conception from + to – and tailed in cell 'D' if there is a change from – to +. This means change in conception before and after intervention occurs only in cells 'A' and 'D'. If there is no change in conception, the student is tailed in cell 'B' if the response is +

both before and after intervention and tailed in cell 'C' if the response is – both before and after intervention. From these, the McNemar formula is given by

$$\chi^2 = \frac{(|A - D| - 1)^2}{A + D}$$

With df = 1

This formula is used to calculate the degree of change in students' alternative conception from pre-test to the post-test 1, from post-test 1 to the post-test 2 and from post-test 2 to the post-test 3. For an observed critical value for equal to or greater than 3.84 at $\alpha = .05$ for a particular significance level of $df = 1$, the implication is that a significant effect has taken place after the intervention.

APPENDIX O

OPEN ENDED QUESTIONNAIRE FOR CHEMISTRY TEACHERS ON WRITING OF CHEMICAL FORMULAE

Over the years, the West African Examinations Council Chief Examiners' reports in chemistry have consistently alluded to students' inability to write correct chemical formulae in the SSSCE or WASSCE chemistry examinations.

This study therefore seeks to find out issues connected with the teaching and learning of this topic. Please your responses will be treated confidential and used only for research purposes. Your identity is not needed hence respond to the items as truthfully as possible.

1. What do you consider as central ideas to writing of chemical formulae?
2. What are the difficulties/limitations connected with teaching this topic.
3. What are the difficulties/limitations connected with learning this topic.
4. What teaching procedures do you use to help your students understand this topic
5. How do you ascertain students' understanding of this topic

APPENDIX P

OPEN ENDED QUESTIONNAIRE FOR CHEMISTRY TEACHERS ON WRITING OF CHEMICAL EQUATIONS

Over the years, the West African Examinations Council Chief Examiners' reports in chemistry have consistently alluded to students' inability to write correct chemical equations in the SSSCE or WASSCE chemistry examinations.

This study therefore seeks to find out issues connected with the teaching and learning of this topic. Please your responses will be treated confidential and used only for research purposes. Your identity is not needed hence respond to the items as truthfully as possible.

1. What do you consider as central ideas to writing chemical equations of combination, displacement and metathesis rections.
2. What are the difficulties/limitations connected with teaching this topic.
3. What are the difficulties/limitations connected with learning this topic.
4. What teaching procedures do you use to help your students understand this topic
5. How do you ascertain students' understanding of this topic.

APPENDIX Q

Difficulty and Discrimination Indices of Chemical Formulae Pre-Test for all SHS 2 & 1 Classes who took the Pre-Test

Q/No	Right	Wrong	N	p	q	pq	Upper (U)	Lower (L)	(U-L)/53
1(a)	49	148	197	0.25	0.75	0.19	25	9	0.30
1(b)	73	124	197	0.37	0.63	0.23	45	15	0.57
1(c)	33	164	197	0.17	0.83	0.14	20	5	0.28
1(d)	16	181	197	0.08	0.92	0.07	9	3	0.11
1(e)	50	147	197	0.25	0.75	0.19	20	3	0.32
2(a)	18	179	197	0.09	0.91	0.08	8	1	0.13
2(b)	17	180	197	0.09	0.91	0.08	9	1	0.15
2(c)	9	188	197	0.05	0.95	0.05	3	1	0.04
2(d)	7	190	197	0.04	0.96	0.04	3	1	0.04
2(e)	18	179	197	0.09	0.91	0.08	6	1	0.09
3(a)	56	141	197	0.28	0.72	0.20	28	6	0.42
3(b)	52	145	197	0.26	0.74	0.19	26	4	0.42
3(c)	13	184	197	0.07	0.93	0.07	4	1	0.06
3(d)	12	185	197	0.06	0.94	0.06	5	1	0.08
3(e)	38	159	197	0.19	0.81	0.15	15	5	0.19
4(a)	52	145	197	0.26	0.74	0.19	26	4	0.42
4(b)	49	148	197	0.25	0.75	0.19	22	6	0.30
4(c)	15	182	197	0.08	0.92	0.07	5	1	0.08
4(d)	19	178	197	0.10	0.90	0.09	6	1	0.09
4(e)	33	164	197	0.17	0.83	0.14	15	3	0.23
5(a)	86	111	197	0.44	0.56	0.25	36	9	0.51
5(b)	60	137	197	0.30	0.70	0.21	22	5	0.32
5(c)	9	188	197	0.05	0.95	0.05	5	1	0.08
5(d)	11	186	197	0.06	0.94	0.06	5	1	0.08
5(e)	46	151	197	0.23	0.77	0.18	16	4	0.23
6(a)	70	127	197	0.36	0.64	0.23	31	6	0.47
6(b)	59	138	197	0.30	0.70	0.21	28	4	0.45
6(c)	18	179	197	0.09	0.91	0.08	8	1	0.13
6(d)	11	186	197	0.06	0.94	0.06	5	1	0.08
6(e)	53	144	197	0.37	0.63	0.23	26	4	0.42
7(a)	33	164	197	0.17	0.83	0.14	15	3	0.23
7(b)	27	170	197	0.14	0.86	0.12	9	2	0.13
7(c)	6	191	197	0.03	0.97	0.03	2	1	0.02
7(d)	7	190	197	0.04	0.96	0.04	3	1	0.04
7(e)	26	171	197	0.13	0.87	0.11	8	2	0.11
8(a)	38	159	197	0.19	0.81	0.15	15	4	0.21
8(b)	29	168	197	0.15	0.85	0.13	10	2	0.15

Q/No	Right	Wrong	N	p	q	pq	Upper (U)	Lower (L)	(U-L)/53
8(c)	8	189	197	0.04	0.96	0.04	3	1	0.04
8(d)	7	190	197	0.04	0.96	0.04	2	1	0.02
8(e)	20	177	197	0.10	0.90	0.09	6	1	0.09
9(a)	25	172	197	0.13	0.87	0.11	8	1	0.13
9(b)	24	173	197	0.12	0.88	0.11	8	1	0.13
9(c)	3	194	197	0.02	0.98	0.02	1	1	0.00
9(d)	5	192	197	0.03	0.97	0.03	2	1	0.02
9(e)	35	162	197	0.18	0.82	0.15	15	3	0.23
				mean = 0.16		∑pq = 5.37			mean = 0.19

KR-20 Calculation of Chemical Formulae Pre-Test

Standard deviation (S) of chemical formulae pre-test = 18.38

Hence Variance (S^2) of chemical formulae pre-test = 337.824

$$\text{KR-20} = \frac{n}{n-1}\left[1 - \frac{\sum pq}{S^2}\right]$$

Where

n = total number of items in the chemical formulae pre-test

p = proportion of students who had the item correct

q = proportion of students who had the item wrong

Hence,

$$\text{KR-20} = \frac{45}{44}\left[1 - \frac{5.37}{337.824}\right]$$

$= 1.023[1 - 0.016]$

$= 1.023[0.984]$

$= 1.0$

APPENDIX R

Difficulty and Discrimination Indices of Chemical Equations Pre-Test for all SHS 2 & 1 Classes who took the Pre-Test

Q/No	Right	Wrong	N	p	q	pq	Upper (U)	Lower (L)	(U-L)/53
1	56	141	197	0.28	0.72	0.20	32	6	0.49
2	48	149	197	0.24	0.76	0.18	28	4	0.45
3	22	175	197	0.11	0.89	0.10	8	1	0.13
4	62	135	197	0.31	0.69	0.21	37	6	0.58
5	30	167	197	0.15	0.85	0.13	14	2	0.23
6	19	178	197	0.10	0.90	0.09	10	1	0.17
				mean = 0.20		$\sum pq$ = 0.91			mean = 0.34

KR-20 Calculation of Chemical Equations Pre-Test

Standard deviation (S) of chemical equations pre-test = 2.11

Hence Variance (S^2) of chemical equations pre-test = 4.452

$$\text{KR-20} = \frac{n}{n-1}\left[1 - \frac{\sum pq}{S^2}\right]$$

Where

n = total number of items in the chemical equations pre-test

p = proportion of students who had the item correct

q = proportion of students who had the item wrong

Hence,

$$\text{KR-20} = \frac{6}{5}\left[1 - \frac{0.91}{4.452}\right]$$

$= 1.2[1 - 0.204]$

$= 1.2[0.796]$

$= 0.96$

APPENDIX S

Students' wrong responses for the chemical formula of Iron (III) trixoxocarbonate (IV)

SHS 2(N=73)		SHS1(N=75)	
Formulae given by students	No & % of students	Formulae given by students	No & % of students
$FeCO_3$	40 (54.8%)	Fe_2CO_3	25 (33.3%)
$Fe_2(CO_2)_3$	12 (16.4%)	$FeCO_3$	18 (24.0%)
Fe_3CO_3	9 (9.6%)	Fe_3CO_2	12 (16.0%)
Fe_3CO_4	1 (1.4%)	Fe_3CaO_2	3 (4.0%)
Fe_2CO_3	2 (2.7%)	$Fe(CO_2)_3$	6 (8.0%)
$Fe_3(CO_2)_4$	1 (1.4%)	Fe^3 CO^3	1 (1.3%)
$Fe(CO_2)_3$	1 (1.4%)	Fe_33C	1 (1.3%)
$Fe_2CO_3^{2-}$	1 (1.4%)	$Fe_3(CO2)_3$	4 (5.3%
$Fe_2(CO_3)_2$	2(2.7%)	Fe_3CO_4	5 (6.7%)
$Fe(CO_3)_3$	1 (1.4%)		
$Fe_2(CO_3)$	3 (4.1%)		

APPENDIX T

Students' wrong responses for the chemical formula of Silver nitride

SHS 2(N = 90)		SHS1(N = 89)	
Formulae given by students	No & % of students	Formulae given by students	No & % of students
AgN	30 (33.3%)	Ag $(NO_2)_2$	32 (36.0%)
$AgNO_3$	16 (17.8%)	$AgNO_3$	16 (18.0)
Ag_2N	10 (11.1%)	AgN	22 (22.4%)
Ag_3N_3	5 (5.6%)	Ag_3NO_2	4 (4.5%)
$AgNO_2$	13 (14.4%)	AgN_2	4 (4.5%)
Ag_3N_2	4 (4.4%)	Ag_2N	2 (2.2%)
$SnNO_2$	2 (2.2%)	Hg NO_3	1 (1.1%)
Au_3N_2	2 (2.2%)	AuN	1 (1.1%)
No Answer	8 (8.9%)	Ag_3N_2	4 (4.5%)
		Ag_2NO_3	3 (3.4%)

APPENDIX U

Students' wrong responses for the chemical formula of Iron (III) tetraoxosulphate (VI)

SHS 2(N = 67)		SHS1(N = 74)	
Formulae given by students	No & % of students	Formulae given by students	No & % of students
Fe_3SO_4	28 (41.8%)	Fe_3SO_4	25 (33.8%)
Fe_2SO_4	9 (13.4%)	$Fe_3\ (S_6)_4$	18 (24.3%)
$Fe_2(SO_4)_2$	6 (9.0%)	Fe_3CO_4	15 (20.3%)
$Fe_2(SO_4)_3$	8 (11.9%)	$(Fe_3)_2SO_4$	8 (10.8%)
$FeSO_4$	7 (10.4%)	Fe_2SO_4	8 (10.8%)
FeS	2 (3.0%)		
$FeSO_3$	4 (6.0%)		
No Answer	3 (4.5%)		

APPENDIX V

Students' wrong responses for the chemical formula of Ammonium trioxocarbonate (IV)

SHS 2(N = 69)		SHS1(N = 76)	
Formulae given by students	No & % of students	Formulae given by students	No & % of students
NH_4CO_3	40 (60.0%)	NH_4CO_3	31 (40.8%)
NH_3CO_3	11 (15.9%)	NH_2CO	18 (23.7%)
$NH_4(CO_3)_2$	4 (5.8%)	NH_3CO_3	11 (14.5%)
NH_4CO_4	3 (4.3%)	NO_3CO_3	3 (3.9%)
NH_4CO_3	5 (7.2%)	NH_3CO_4	3 (3.9%)
NH_2CO_3	4 (5.8%)	$NH_4(CO_3)_2$	6 (7.9%)
$NH_3(CO_3)_4$	2 (2.9%)	$(NH_4)_4(CO_3)$	4 (5.3%)

APPENDIX W

Students' wrong responses for the chemical formula of Lithium trioxocarbonate (IV)

SHS 2(N = 57)		SHS1(N = 54)	
Formulae given by students	No & % of students	Formulae given by students	No & % of students
$LiCO_3$	35 (61.4%)	$LiCO_3$	20 (37.0%)
$LiCO_2$	2 (3.5%)	Li_3CO_4	4 (7.4%)
$Li(CO_3)_2$	6 (10.5%)	Li_2SO_3	3 (5.6%)
Li_3CO_4	4 (7.0%)	Li_3CO_3	11 (20.4%)
Li_3CO_3	3 (5.3%)	$Li_3\ (CO_4)_3$	4 (7.4%)
No Answer	7 (12.3%)	$Li_2(CO_3)_3$	5 (9.3%)
		$LiCO_3$ (IV)	1 (1.9%)
		No Answer	6 (11.1%)

APPENDIX X

Students' wrong responses for the chemical formula of Aluminium tetraoxosulphate (VI)

SHS 2(N = 60)		SHS1(N = 67)	
Formulae given by students	No & % of students	Formulae given by students	No & % of students
Al_2SO_4	25 (41.7%)	$AlSO_4$	15 (22.4%)
$AlSO_4$	17 (28.3%)	AlH_2SO_4	12 (17.9%)
$Al(SO_4)_3$	9 (15.0%)	Al_3SO_4	11 (16.4%)
$Al_3(SO_4)_2$	4 (6.7%)	Al_2SO_4	8 (11.9%)
Al_3SO_4	3 (5.0%)	$Al\ (SO_4)$	9 (13.4%)
Al_2SO_3	2 (3.3%)	$Al_6(SO_4)$	4 (6.0%)
		$Al(S_4)_6$	2(3.0%)
		No answer	6 (9.0%)

APPENDIX Y

Students' wrong responses for the chemical formula of Copper (II) tetraoxophosphate (V)

SHS 2(N = 74)		SHS1(N = 90)	
Formulae given by students	No & % of students	Formulae given by students	No & % of students
$CuPO_4$	40 (54.1%)	$CuPO_4$	28 (31.1%)
Cu_2PO_4	13 (17.6%)	$CuSO_4$	25 (27.8%)
Cu_3PO_4	10 (13.5%)	CuPO	10 (11.1%)
$Cu_2(PO_4)_2$	5 (67.6%)	Cu_2PO_3	8 (8.9%)
$CuSO_4$	2 (2.7%)	Cu_3PO_4	3 (3.3%)
$Cu_2(PO_4)_3$	4 (5.4%)	$Cu_2(PO_5)_4$	3 (3.3%)
		$Cu_3(SO_4)_2$	4 (4.4%)
		Cu_2H_2SO	3 (3.3%)
		No answer	6 (6.7%)

APPENDIX Z

Students' wrong responses for the chemical formula of Calcium tetraoxophosphate (V)

SHS 2(N = 75)		SHS1(N = 84)	
Formulae given by students	No & % of students	Formulae given by students	No & % of students
$CaPO_4$	39 (52.0%)	$Ca_3(PO)_4$	25 (29.8%)
Ca_3PO_4	11 (14.7%)	$CaSO_4$	18 (21.4%)
$CaSO_4$	9 (12.0%)	CaH_2SO_4	4 (4.8%)
$Ca_3(SO_4)_2$	3 (4.0%)	$CaPO_3$	10 (11.9%)
$Ca(PO_4)_2$	4 (5.3%)	$CaPO_4$	8 (9.5%)
$Ca(PO_3)_2$	2 (2.7%)	Ca_4PO_5	1 (1.2%)
Ca_2PO_4	1 (1.3%)	$Ca_4(PO_4)$	5 (6.0%)
$CaPO_3$	1 (1.3%)	Ca_2PO_3	3 (3.6%)
NO Answer	5 (6.7%)	$Ca_2\ (PO_4)_2$	1 (1.2%)
		No Answer	9 (10.7%)

APPENDIX A1

Students' wrong responses for the chemical formula of Ammonium sulphide

SHS 2(N = 85)		SHS1(N = 87)	
Formulae given by students	No & % of students	Formulae given by students	No & % of students
NH_4S	35 (41.2%)	NH_4S	30 (34.5%)
NH_4SO_2	15 (17.6%)	$(NH_4)_2 SO_3$	13 (14.9%)
NH_4S_2	3 (3.5%)	NHS	5 (5.7%)
$(NH_4)_3S$	8 (9.4%)	NH_3SO_3	8 (9.2%)
NH_3S	4 (4.7%)	NH_3SO_4	11 (12.6%)
NH_2S_3	1 (1.2%)	NH_4SO	6 (6.9%)
$(NH_3)_2S$	3 (3.5%)	$(NH_4)_2SO_4$	6 (6.9%)
NH_3S_2	1 (1.2%)	NH_4SO_3	2 (2.3%)
$(NH_4)_2S$	3 (3.5%)	NH_4SO_4	6 (6.9%)
No Answer	12 (14.1%)		

APPENDIX B2

Wrong chemical equations given by SHS 2 students for the reaction between: Aluminium metal ion and fluoride ion to form aluminium fluoride (N = 60)

Various equations given by students	Number and percentage of students
$Al^{3+} + F^- \longrightarrow AlF_3$	21 (35.0%)
$Al + 3F \longrightarrow AlF_3$	9 (15.0%)
$Al^{2-} + F^+ \longrightarrow AlF^-$	1 (1.7%)
$2Al^{3+} + F^- \longrightarrow Al_2F$	2 (3.3%)
$Al + F \longrightarrow AlF$	1 (1.7%)
$3Al + F \longrightarrow Al_3F$	1 (1.7%)
$Al_2 + 2F \longrightarrow 2AlF$	1 (1.7%)
$Al_3 + F \longrightarrow Al_3F$	5 (8.3%)
$Al_2 + 4F \longrightarrow 2AlF_2$	1 (1.7%)
$Al_2 + F \longrightarrow AlF_3$	5 (8.3%)
$Al^{3+} + 3F^- \longrightarrow Al_3F$	5 (8.3%)
$2Al + F_2 \longrightarrow 2AlF_2$	1 (1.7%)
$4Al_3 + 9F_2 \longrightarrow 6Al_2F_3$	1 (1.7%)
$Al_2 + F \longrightarrow Al_2F$	1 (1.7%)
$Al_2 + F_2 \longrightarrow Al_2F_2$	1 (1.7%)
$Al^{3+} + Fl_2 \longrightarrow AlFl_2$	1 (1.7%)
$Al^{3+} + 3Fl^- \longrightarrow 2Al_2Fl_3$	2 (3.3%)
$2Al + F \longrightarrow 2AlF$	1 (1.7%)

APPENDIX C3

Wrong chemical equations given by SHS 2 students for the reaction between: Aluminium metal ion and fluoride ion to form aluminium fluoride (N = 60)

Various equations given by students		Number and percentage of students
$Al^{3+} + F^{-}$ →	AlF_3	21 (35.0%)
$Al + 3F$ →	AlF_3	9 (15.0%)
$Al^{2-} + F^{+}$ →	AlF^{-}	1 (1.7%)
$2Al^{3+} + F^{-}$ →	Al_2F	2 (3.3%)
$Al + F$ →	AlF	1 (1.7%)
$3Al + F$ →	Al_3F	1 (1.7%)
$Al_2 + 2F$ →	$2AlF$	1 (1.7%)
$Al_3 + F$ →	Al_3F	5 (8.3%)
$Al_2 + 4F$ →	$2AlF_2$	1 (1.7%)
$Al_2 + F$ →	AlF_3	5 (8.3%)
$Al^{3+} + 3F^{-}$ →	Al_3F	5 (8.3%)
$2Al + F_2$ →	$2AlF_2$	1 (1.7%)
$4Al_3 + 9F_2$ →	$6Al_2F_3$	1 (1.7%)
$Al_2 + F$ →	Al_2F	1 (1.7%)
$Al_2 + F_2$ →	Al_2F_2	1 (1.7%)
$Al^{3+} + Fl_2$ →	$AlFl_2$	1 (1.7%)
$Al^{3+} + 3Fl^{-}$ →	$2Al_2Fl_3$	2 (3.3%)
$2Al + F$ →	$2AlF$	1 (1.7%)

APPENDIX D4

Wrong chemical equations given by SHS 2 students for the reaction between: Iron (II) metal ion and fluoride ion to form iron (II) fluoride (N = 68)

Various equations given by students		Number and percentage of students
$Fe^{2+} + F^{-} \longrightarrow$	Fe_2F	24 (35.3%)
$Fe_2 + F \longrightarrow$	Fe_2F	8 (11.8%)
$Fe + F \longrightarrow$	FeF	4 (5.9%)
$Fe_2 + S \longrightarrow$	Fe_2S	9 (13.2%)
$Fe^{2+} + 2F \longrightarrow$	FeF_2	12 (17.6%)
$Fe_2 + 2F \longrightarrow$	$2FeF$	3 (4.4%)
$Fe^{2+} + S^{2-} \longrightarrow$	FeS	2 (2.9%)
$2Fe + F^{-} \longrightarrow$	Fe_2F	1 (1.5%)
$Fe_2 + F_2 \longrightarrow$	$2FeF$	1 (1.5%)
$Fe^{2+} + S^{2-} \longrightarrow$	FeS	1 (1.5%)
$Fe_2 + F \longrightarrow$	Fe_2F	1 (1.5%)
$Fe_2 + S_2 \longrightarrow$	$2FeF_2$	1 (1.5%)
$Fe^{2+} + F^{-1} \longrightarrow$	FeF	1 (1.5%)

APPENDIX E5

Wrong chemical equations given by SHS 2 students for the reaction between: Potassium hydroxide and tetraoxophosphate (V) acid to form potassium tetraoxophosphate (V) and water (N = 75)

Various equations given by students		Number and percentage of students
$KOH + HPO_3 \longrightarrow$	$K_2PO_3 + H_2O$	11 (14.7%)
$KOH + HPO_4 \longrightarrow$	$K_2PO_4 + 2H_2O$	5 (6.7%)
$K(OH)_2 + H_2PO_4 \longrightarrow$	$KPO_4 + H_2O$	3 (4.0%)
$KHO + PSO_4 \longrightarrow$	$KPSO_4 + H_2O$	2 (2.7%)
$KOH + HPO_4 \longrightarrow$	$KPO_4 + H_2O$	8 (10.7%)
$2KO_2H + PO_4 \longrightarrow$	$2KPO_4 + H_2O$	3 (4.0%)
$K_2OH + H_2PO_4 \longrightarrow$	$K_2PO_4 + H_2O$	2 (2.7%)
$KOH + HPO_4 \longrightarrow$	$KPO_4 + H_2O$	6 (8.0%)
$K(OH)_2 + PO_4 \longrightarrow$	$K(PO_4) + 2H_2O$	3 (4.0%)
$2KOH + H_2PO_4 \longrightarrow$	$K_2PO_4 + 2H_2O$	10 (13.3%)
$KOH + H_3PO_4 \longrightarrow$	$KPO_4 + H_2O$	4 (5.3%)
$KOH + PO_4 \longrightarrow$	$KPO_4 + H_2O$	6 (8.0%)
$KOH + HPO_3 \longrightarrow$	$KPO_3 + H_2O$	7 (9.3%)
$KOH + H_2PO_4 \longrightarrow$	$K_3PO_4 + 3H_2O$	2 (2.7%)
$KOH + HPO_3 \longrightarrow$	$KPO_3 + H_2O$	2 (2.7%)
$KOH + HPSO_4 \longrightarrow$	$KPSO_4 + H_2O$	1 (1.3%)

APPENDIX F6

Wrong chemical equations given by SHS 2 students for the reaction between: Iron (II) metal ion and Copper (II) tetraoxosulphate (VI) to form Iron (II) tetraoxosulphate (VI) and Copper (II) metal (N = 61)

Various equations given by students	Number and percentage of students
$Fe_2 + CuSO_4 \longrightarrow Fe_2SO_4 + Cu_2$	30 (49.2%)
$Fe_2 + Cu_2SO_4 \longrightarrow Fe_2SO_4 + Cu_2$	16 (26.2%)
$Fe_2 + Cu(SO_4)_2 \longrightarrow 2Fe(SO_4)_2 + Cu_2$	8 (13.1%)
$Fe_2 + 2Cu_2SO_4 \longrightarrow Fe_2(SO_4)_2 + Cu_2$	4 (6.6%)
$Fe_2 + Cu_2(SO_4) \longrightarrow Fe_2(SO_4) + Cu_2$	3 (4.9%)

APPENDIX G7

Wrong chemical equations given by SHS 2 students for the reaction between: Copper (II) metal ion and silver trioxonitrate (V) to form copper (II) trioxonitrate (V) and silver metal (N = 77)

Various equations given by students	Number and percentage of students
$Cu + AgNO_3 \longrightarrow CuNO_3 + Ag$	20 (26.0%)
$2Cu^{2+} + AgNO_3 \longrightarrow Cu_2NO_3 + Ag^+$	8 (10.4%)
$Cu_2 + AgNO_3 \longrightarrow CuNO_3 + Ag$	10 (13.0%)
$2Cu_2 + 2AgNO_3 \longrightarrow 2Cu_2NO_3 + Ag_2$	9 (11.7%)
$Cu_2 + Ag_3NO_3 \longrightarrow Cu_2NO_3 + Ag_3$	3 (3.9%)
$Cu + Ag(NO_2) \longrightarrow Cu(NO_2) + Ag$	4 (5.2%)
$Cu^{2+} + Ag_2NO_3 \longrightarrow Cu_2NO_3 + 2Ag^+$	8 (10.4%)
$3Cu_2 + 3SiNO_3 \longrightarrow 3Cu_2 + SiNO_3$	3 (3.9%)
$Cu_2 + AgNO_3 \longrightarrow Cu_2NO_3 + Ag$	6 (7.8%)
$Cu_2 + Ag(NO_3) \longrightarrow Cu(NO_3) + Ag$	3 (3.9%)
$Cu + AgNO_3 \longrightarrow Cu_2NO_3 + Ag$	1 (1.3%)
$Cu_2 + AgNO \longrightarrow Cu_2NO_3$	1 (1.3%)
$Cu + SnNO_3 \longrightarrow CuNO_3 + Sn$	1 (1.3%)

APPENDIX H8

Wrong chemical equations given by SHS 2 students for the reaction between: Potassium tetraoxochromate (VI) with lead trioxonitrate (V) to form lead tetraoxochromate (VI) and potassium trioxonitrate (V) (N = 81)

Various equations given by students	Number and percentage of students
$K_2CrO_4 + 2PbNO_3 \longrightarrow PbCrO_4 + 2KNO_3$	25 (30.9%)
$KCrO_4 + 2PbNO_3 \longrightarrow Pb_2CrO_4 + KNO_3$	5 (6.2%)
$KCrO_4 + PbNO_3 \longrightarrow PbCrO_4 + KNO_3$	8 (9.9%)
$KCr_2O_4 + PbNO_3 \longrightarrow PbCr_2O + KNO_3$	8 (9.9%)
$2KCrO_4 + Pb(NO_3) \longrightarrow Pb(Cr_3) + KNO_3$	5 (6.2%)
$KCrO_4 + PbNO_3 \longrightarrow PbCrO_4 + KNO_3$	6 (7.4%)
$K_2CrO_4 + PbNO_3 \longrightarrow PbCrO_4 + K_2NO_3$	5 (6.2%)
$K(Cr_4) + Pb(NO_3) \longrightarrow Pb(Cr_4) + KNO_3$	2 (2.5%)
$K_2CrO_4 + Pb(NO_3)_2 \longrightarrow Pb(CrO_4)_2 + 2KNO_3$	6 (7.4%)
$KCrO_4 + PbNO_3 \longrightarrow PbCrO_4 + K_2NO_3$	5 (6.2%)
$K_2CrO_4 + PbNO_3 \longrightarrow Pb_2CrO_4 + K_2NO_3$	2 (2.5%)
$KCrO_4 + PbNO_3 \longrightarrow PbCrO_4 + KNO_3$	2 (2.5%)
$KCrO_7 + PbNO_3 \longrightarrow PbCrO_7 + KNO_3$	2 (2.5%)

APPENDIX I9

Wrong chemical equations given by SHS 1 students for the reaction between:

Aluminium metal ion and fluoride ion to form aluminium fluoride (N = 75)

Various equations given by students	Number and percentage of students
$Al + F_3 \longrightarrow AlF_3$	20 (26.7%)
$Al + F \longrightarrow AlF_2$	5 (6.7%)
$Al + Fl \longrightarrow AlFl_3$	16 (21.3%)
$Al + 3F \longrightarrow AlF_3$	11 (14.7%)
$2Al + Fl \longrightarrow Al_2Fl$	6 (8.0%)
$Al + Fl \longrightarrow AlFl$	10 (13.3%)
$Al_2 + Fl_2 \longrightarrow Al_2Fl_2$	3 (4.0%)
$Al^{3+} + Fl^{-} \longrightarrow 2AlFl_3$	4 (5.3%)

APPENDIX J10

Wrong chemical equations given by SHS 1 students for the reaction between:

Iron (II) metal ion and fluoride ion to form iron (II) fluoride (N = 75)

Various equations given by students	Number and percentage of students
$Fe + F_2 \longrightarrow FeF_2$	26 (34.7%)
$Fe_2 + Fl \longrightarrow FeFl_2$	12 (16.0%)
$Fe + 2F \longrightarrow FeF_2$	10 (13.3%)
$Fe_2 + SO_3 \longrightarrow 2FeSO_3$	4 (5.3%)
$Fe + Fl \longrightarrow FeFl$	15 (20.0%)
$Fe_2 + 2Fl \longrightarrow 2FeFl$	5 (6.7%)
$Fe_3 + Fl \longrightarrow Fe_3Fl$	1 (1.3%)
$2Fe + Fl_2 \longrightarrow 2FeFl_2$	1 (1.3%)
$Fe_2 + Fl_2 \longrightarrow 2FeFl$	1 (1.3%)

APPENDIX K11

Wrong chemical equations given by SHS 1 students for the reaction between: Potassium hydroxide and tetraoxophosphate (V) acid to form potassium tetraoxophosphate (V) and water (N = 94)

Various equations given by students	Number and percentage of students
$KOH + PO_4 \longrightarrow KPO_4 + \frac{1}{2} H_2O$	30 (31.9%)
$KOH + HPO_4 \longrightarrow K_4P + 2H_2O$	24 (25.5%)
$KOH + H_2PO_4 \longrightarrow K_2PO_4 + H_2O$	20 (21.3%)
$KOH + H_2PO_3 \longrightarrow KPO_3 + H_2O$	8 (8.5%)
$KOH + PO \longrightarrow KPO + H_20$	6 (6.4%)
$K(OH)_2 + PO_4 \longrightarrow K_3PO_4 + H_2O$	3 (3.2%)
$KOH+HSO_4 \longrightarrow K(OH)_2S$	2 (2.1%)
$5KO_2+2PO_5 \longrightarrow 2KO_5PO_2$	1 (1.1%)

APPENDIX L12

Wrong chemical equations given by SHS 1 students for the reaction between: Iron (II) metal ion and Copper (II) tetraoxosulphate (VI) to form Iron (II) tetraoxosulphate (VI) and Copper (II) metal (N = 68)

Various equations given by students	Number and percentage of students
$Fe_2 + Cu_2SO_4 \longrightarrow Fe_2SO_4 + Cu_2$	33 (48.5%)
$Fe_2 + CuSO_4 \longrightarrow Fe_2SO_4 + Cu_2$	28 (41.2%)
$Fe_2 + Cu_2S_4 \longrightarrow Fe_2S_4 + Cu_2$	5 (7.4%)
No response	2 (2.9%)

APPENDIX M13

Wrong chemical equations given by SHS 1 students for the reaction between: Copper (II) metal ion and silver trioxonitrate (V) to form copper (II) trioxonitrate (V) and silver metal (N = 84)

Various equations given by students			Number and percentage of students
Cu_2 + $AgNO_3$	⟶	Cu_2NO_3 + Ag	28 (33.3%)
Cu + Ag (NO_3)	⟶	$CuNO_3$ + Ag	16 (19.0%)
Cu_2 + $Ag(NO_3)_2$	⟶	$Cu_2(NO_4)_3$ + Ag	21 (25.0%)
Cu_2 + Ag_3NO_5	⟶	Cu_2NO_5 + Ag	5 (6.0%)
Cu + AgNOH	⟶	Cu NOH + Ag	2 (2.4%)
2Cu + Ag_2NO_3	⟶	Cu_2NO_3 + Ag	5 (6.0%)
Cu + Ag $(NO_3)_2$	⟶	$Cu(NO3)_2$ + Ag	3 (3.6%)
Cu + $AgNO_3$	⟶	$CuNO_3$ + Ag	4 (4.8%)

APPENDIX N14

Wrong chemical equations given by SHS 1 students for the reaction between: Potassium tetraoxochromate (VI) and lead trioxonitrate (V) to form lead tetraoxochromate (VI) and potassium trioxonitrate (V) (N = 91)

Various equations given by students			Number and percentage of students
$KCrO_4 + PbNO_3$	$\longrightarrow$	$PbCr\ O_4 + KNO_3$	35 (38.5%)
$K_2CrO_4 + PbNO_3$	$\longrightarrow$	$PbCrO_4 + K_2NO_3$	24 (26.4%)
$KCrO_7 + Pb(NO_3)_2$	$\longrightarrow$	$PbCrO_7 + KNO_3$	20 (22.0%)
$K(Cr_4)_3 + Pb(NO_5)_3$	$\longrightarrow$	$Pb\ (Cr_7)_3 + K(NO_3)_3$	8 (8.8%)
$KH_2O + PbNO_3$	$\longrightarrow$	$PbH_2O + KNO_3$	4 (4.4%)

APPENDIX O15

Changes in Students' Conceptions in Chemical Formulae from Pre-test to 3rd Post-test

	SHS 2A Class [N = 36]							SHS 1A Class [N = 25]						
Question	A	B	C	D	Pretest	Posttest	χ^2	A	B	C	D	Pretest	Posttest	χ^2
1(a)	0	20	2	14	16(44.4)	2(5.6)	12.071*	1	11	0	13	13(52.0)	1(4.0)	8.643*
1(b)	0	21	2	13	15(41.7)	2(5.6)	11.077*	1	13	0	11	11(44.0)	1(4.0)	6.750*
1(c)	2	19	3	12	15(41.7)	5(13.9)	5.786*	2	11	2	10	12(48.0)	4(16.0)	4.083*
1(d)	2	19	3	12	15(41.7)	5 (13.9)	5.786*	2	11	2	10	12(48.0)	2(8.0)	4.083*
1(e)	2	16	4	14	18(50.0)	6(16.7)	5.786*	2	10	0	13	13(52.0)	2(8.0)	6.667*
2(a)	0	20	0	16	16(44.4)	0(0.0)	14.063*	0	14	0	11	11(44.0)	0(0.0)	9.091*
2(b)	0	20	0	16	16(44.4)	0(0.0)	14.063*	0	13	2	10	12(48.0)	2(8.0)	8.100*
2(c)	0	21	0	15	15(41.7)	0(0.0)	13.067*	0	13	2	10	12(48.0)	2(8.0)	8.100*
2(d)	0	21	0	15	15(41.7)	0(0.0)	13.067*	0	13	2	10	12(48.0)	2(8.0)	8.100*
2(e)	0	21	0	15	15(41.7)	0(0.0)	13.067*	0	13	2	10	12(48.0)	2(8.0)	8.100*

Figures in parenthesis are percentages *Significant at $\chi^2 \geq 3.84$

APPENDIX O13 Cont'd

Changes in Students' Conceptions in Chemical Formulae from Pre-test to 3rd Post-test

	SHS 2A Class [N = 36]							SHS 1A Class [N = 25]						
Question	A	B	C	D	Pretest	Posttest	χ^2	A	B	C	D	Pretest	Posttest	χ^2
3(a)	0	11	0	25	25(69.4)	0(0.0)	23.040 *	2	3	0	20	20(80.0)	2 (8.0)	13.136 *
3(b)	0	11	0	25	25(69.4)	0(0.0)	23.040*	2	3	0	20	20(80.0)	2(8.0)	13.136*
3(c)	0	11	0	25	25(69.4)	0(0.0)	23.040*	2	3	0	20	20(80.0)	2(8.0)	13.136*
3(d)	0	11	0	25	25(69.4)	0(0.0)	23.040*	2	3	0	20	20(80.0)	2(8.0)	13.136*
3(e)	0	11	0	25	25(69.4)	0(0.0)	23.040*	2	3	0	20	20(80.0)	2(8.0)	13.136*
4(a)	0	20	2	14	16(44.4)	2(5.6)	12.071*	0	15	0	10	10(40.0)	0(0.0)	8.100*
4(b)	0	24	0	12	12(33.3)	0(0.0)	10.083*	0	15	0	10	10(40.0)	0(16.0)	8.100*
4(c)	2	22	0	12	12(33.3)	2(5.6)	5.786 *	0	16	0	9	9(36.0)	0(0.0)	7.111*
4(d)	2	22	0	12	12(33.3)	2(5.6)	5.786*	0	16	0	9	9(36.0)	0(0.0)	7.111*
4(e)	2	22	0	12	12(33.3)	2(5.6)	5.786*	0	16	0	9	9(36.0)	0(0.0)	7.111*

Figures in parenthesis are percentages *Significant at $\chi^2 \geq 3.84$

APPENDIX O15 Cont'd

Changes in Students' Conceptions in Chemical Formulae from Pre-test to 3rd Post-test

	SHS 2A Class [N = 36]							SHS 1A Class [N = 25]						
Question	A	B	C	D	Pretest	Posttest	χ^2	A	B	C	D	Pretest	Posttest	χ^2
5(a)	2	14	0	20	20(55.6)	2(5.6)	13.136*	2	8	0	15	15(60.0)	2(8.0)	8.471*
5(b)	2	15	0	19	19(52.8)	2(5.6)	12.190*	2	8	0	15	15(60.0)	2(8.0)	8.471*
5(c)	2	15	0	19	19(52.8)	2(5.6)	12.190*	2	8	0	15	15(60.0)	2(8.0)	8.471*
5(d)	2	15	0	19	19(52.8)	2(5.6)	12.190*	2	8	0	15	15(60.0)	2(8.0)	8.471*
5(e)	2	15	0	19	19(52.8)	2(5.6)	12.190*	2	8	0	15	15(60.0)	2(8.0)	8.471*
6(a)	0	24	0	12	12(33.3)	0(0.0)	10.083*	0	17	0	8	8(32.0)	0(0.0)	6.125*
6(b)	0	27	0	9	9(25.0)	0(0.0)	7.111*	0	18	0	7	7(28.0)	0(0.0)	5.143*
6(c)	0	27	0	9	9(25.0)	0(0.0)	7.111*	0	16	2	7	9(36.0)	2(8.0)	5.143*
6(d)	0	27	0	9	9(25.0)	0(0.0)	7.111*	0	16	2	7	9(36.0)	2(8.0)	5.143*
6(e)	0	27	0	9	9(25.0)	0(0.0)	7.111*	0	13	0	7	7(28.0)	7(28.0)	5.143*

Figures in parenthesis are percentages *Significant at $\chi^2 \geq 3.84$

APPENDIX O15 Cont'd

Changes in Students' Conceptions in Chemical Formulae from Pre-test to 3rd Post-test

	SHS 2A Class [N = 36]							SHS 1A Class [N = 25]						
Question	A	B	C	D	Pretest	Posttest	χ^2	A	B	C	D	Pretest	Posttest	χ^2
7(a)	0	16	0	20	20(55.6)	(0.0)	18.050*	0	13	0	12	12(48.0)	0(0.0)	10.083*
7(b)	0	16	0	20	20(55.6)	0(0.0)	18.050*	0	13	0	12	12(48.0)	0(0.0)	10.083*
7(c)	0	16	0	20	20(55.6)	0(0.0)	18.050*	0	13	0	12	12(48.0)	0(0.0)	10.083*
7(d)	0	16	0	20	20(55.6)	0(0.0)	18.050*	0	13	0	12	12(48.0)	0(0.0)	10.083*
7(e)	0	16	0	20	20(55.6)	0(0.0)	18.050*	0	13	0	12	12(48.0)	0(0.0)	10.083*
8(a)	2	16	10	8	18(50.0)	12(3.3)	2.500	2	8	10	5	15(60.0)	12(4.8)	0.572
8(b)	2	17	8	9	17(47.2)	10(2.7)	3.273	2	8	10	5	15(60.0)	12(4.8)	0.572
8(c)	2	19	8	7	15(41.7)	9(2.7)	1.778	2	8	10	5	15(60.0)	12(4.8)	0.572
8(d)	2	19	8	7	15(41.7)	9(2.7)	1.778	2	8	10	5	15(60.0)	12(4.8)	0.572
8(e)	2	18	8	7	15(41.7)	9(25.0)	1.778	2	7	10	5	15(60.0)	13(36.1)	0.125

Figures in parenthesis are percentages *Significant at $\chi^2 \geq 3.84$

APPENDIX O15 Cont'd

Changes in Students' Conceptions in Chemical Formulae from Pre-test to 3rd Post-test

					SHS 2A Class [N = 36]							SHS 1A Class [N = 25]		
Question	A	B	C	D	Pretest	Posttest	χ^2	A	B	C	D	Pretest	Posttest	χ^2
9(a)	0	4	0	32	32(88.9)	0(0.0)	30.031*	1	2	0	22	22(88.0)	1(4.0)	17.391*
9(b)	0	4	0	32	32(88.9)	0(0.0)	30.031*	1	2	0	22	22(88.0)	1(4.0)	17.391*
9(c)	0	4	0	32	32(88.9)	0(0.0)	30.031*	1	2	0	22	22(88.0)	1(4.0)	17.391*
9(d)	0	4	0	32	32(88.9)	0(0.0)	30.031*	1	2	0	22	22(88.0)	1(4.0)	17.391*
9(e)	0	4	0	32	32(88.9)	0(0.0)	30.031*	1	2	0	22	22(88.0)	1(4.0)	17.391*

Figures in parenthesis are percentages *Significant at $\chi^2 \geq 384$

APPENDIX P16

Changes in Students' Conceptions in Chemical Equations from Pre-test to 3rd Post-test

	SHS 2A Class [N = 36]							SHS 1A Class [N = 25]						
Question	A	B	C	D	Pretest	Posttest	χ^2	A	B	C	D	Pretest	Posttest	χ^2
1	0	13	0	23	20(55.6)	0(0.0)	21.043*	0	10	0	15	15(60.0)	0(0.0)	13.067*
2	0	10	0	26	26(72.2)	0(0.0)	24.038*	1	10	0	14	14(56.0)	1(0.0)	9.600*
3	0	16	0	20	20(55.6)	0(0.0)	18.050*	0	5	0	20	20(80.0)	0(0.0)	18.050*
4	0	16	0	20	20(55.6)	0(0.0)	18.050*	1	8	0	16	16(64.0)	0(0.0)	11.523*
5	1	17	0	18	18(50.0)	1(2.7)	13.474*	2	8	0	15	15(60.0)	2(0.0)	8.471*
6	0	20	0	16	16(44.4)	0(0.0)	14.063*	2	10	0	13	13(52.0)	2(0.0)	6.667*

Figures in parenthesis are percentages *Significant at $\chi^2 \geq 3.84$

APPENDIX Q17

Changes in Validation Students' Conceptions in Chemical Formulae from Pre-test to Post-test

					Validation SHS 1 Class [N = 40]		
Question	A	B	C	D	Pretest	Posttest	χ^2
1(a)	3	7	1	29	30(72.5)	4(10.0)	19.53*
1(b)	3	7	1	29	30(72.5)	4(10.0)	19.531*
1(c)	4	6	1	29	30(72.5)	5(12.5)	17.455*
1(d)	4	6	1	29	30(72.5)	5(12.5)	17.455*
1(e)	1	8	2	29	31(77.5)	3(7.5)	24.300*
2(a)	0	5	3	32	35(87.5)	3(7.5)	30.031*
2(b)	3	5	0	32	32(80.0)	3(7.5)	22.400*
2(c)	2	4	2	32	34(85.0)	4(10.0)	27.735*
2(d)	0	5	3	32	35(87.5)	3(7.5)	30.031*
2(e)	1	6	1	32	33(82.5)	2(5.0)	27.273*
3(a)	2	5	0	33	33(82.5)	2(5.0)	25.714*
3(b)	2	5	0	33	33(82.5)	2(5.0)	25.714*
3(c)	1	5	1	33	34(85.0)	2(5.0)	28.265*
3(d)	2	4	1	33	34(85.0)	3(7.5)	27.714*
3(e)	0	5	2	33	35(87.5)	2(5.0)	31.030*

Figures in parenthesis are percentages *Significant at $\chi^2 \geq 3.84$

APPENDIX Q17 Cont'd

Changes in Validation Students' Conceptions in Chemical Formulae from Pre-test to Post-test

	Validation SHS 1 Class [N = 40]						
Question	A	B	C	D	Pretest	Posttest	χ^2
4(a)	1	4	0	35	35(87.5)	1(2.5)	30.250*
4(b)	1	4	0	35	35(87.5)	1(2.5)	30.250*
4(c)	0	4	1	35	36(90.0)	1(2.5)	33.029*
4(d)	1	3	1	35	36(90.0)	2(5.0)	30.250*
4(e)	1	3	1	35	36(90.0)	2(5.0)	30.250*
5(a)	0	4	0	36	36(90.0)	0(00.0)	34.028*
5(b)	0	4	0	36	36(90.0)	0(00.0)	34.028*
5(c)	1	3	0	36	36(90.0)	1(2.5)	31.243*
5(d)	0	3	1	36	37(92.5)	1(2.5)	34.028*
5(e)	0	4	0	36	36(90.0)	0(00.0)	34.028*
6(a)	0	0	0	40	40(100.0)	0(00.0)	38.025*
6(b)	0	0	0	40	40(100.0)	0(00.0)	38.025*
6(c)	0	0	0	40	40(100.0)	0(00.0)	38.025*
6(d)	0	0	0	40	40(100.0)	0(00.0)	38.025*
6(e)	0	0	0	40	40(100.0)	0(00.0)	38.025*

Figures in parenthesis are percentages *Significant at $\chi^2 \geq 3.84$

APPENDIX Q17 Cont'd

Changes in Validation Students' Conceptions in Chemical Formulae from Pre-test to Post-test

	Validation SHS 1 Class [N = 40]						
Question	A	B	C	D	Pretest	Posttest	χ^2
7(a)	0	4	0	36	36(90.0)	0(00.0)	34.028*
7(b)	1	3	0	36	36(90.0)	1(2.5)	31.243*
7(c)	1	3	0	36	36(90.0)	1(2.5)	31.243*
7(d)	0	3	1	36	37(92.5)	1(2.5)	34.028*
7(e)	0	3	1	36	37(92.5)	1(2.5)	34.028*
8(a)	2	8	1	29	30(75.0)	3(7.5)	21.806*
8(b)	1	8	2	29	31(77.5)	3(7.5)	24.300*
8(c)	2	7	2	29	31(77.5)	4(10.0)	21.806*
8(d)	2	6	3	29	32(80.0)	5(12.5)	21.806*
8(e)	1	8	2	29	31(77.5)	3(7.5)	24.300*
9(a)	4	10	5	21	26(65.0)	9(22.5)	10.240*
9(b)	4	10	5	21	26(65.0)	9(22.5)	10.240*
9(c)	5	9	5	21	26(65.0)	10(25.0)	8.654*
9(d)	4	11	4	21	25(62.5)	8(20.0)	10.240*
9(e)	3	13	3	21	24(60.0)	6(15.0)	12.042*

Figures in parenthesis are percentages *Significant at $\chi^2 \geq 3.84$

APPENDIX R18

Changes in Validation Students' Conceptions in Chemical Equations from Pre-test to Post-test

	Validation SHS 1 Class [N = 40]						
Question	A	B	C	D	Pretest	Posttest 1	χ^2
1	0	0	0	40	40(100.0)	0(00.0)	38.025*
2	2	4	2	32	34(85.0)	4(10.0)	24.735*
3	3	6	3	28	31(77.5)	6(15.0)	18.581*
4	3	10	4	23	27(67.5)	7(17.5)	13.885*
5	2	6	2	30	32(80.0)	4(10.0)	22.781*
6	3	7	2	28	30(75.0)	5(12.5)	18.581*

Figures in parenthesis are percentages *Significant at $\chi^2 \geq 3.84$