UNIVERSITY OF EDUCATION, WINNEBA

STUDENTS' MENTAL MODELS OF CHEMICAL REACTIONS AND BALANCING OF CHEMICAL EQUATIONS: A CASE STUDY OF A GHANAIAN SENIOR HIGH SCHOOL

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DECLARATION

Student's Declaration

I, **SAMPSON MENSAH AKROSUMAH**, declare that this Thesis, with the exception of quotations and references contained in published works which have all been identified and acknowledged, is entirely my own original work and it has not been submitted, either in part or whole, to any institution anywhere for any academic purposes.

Sign ……………………………………Date……………………………..

Supervisors' Declaration

We hereby declare that the preparation and presentation of this thesis was supervised in accordance with the guidelines set for thesis laid down by the University of Education, Winneba.

Sign …………………………....   Date……………………………..

Professor Mawuadem Koku Amedeker

(Principal Supervisor)

Sign…………………………..   Date………………………………

Dr. Victor Antwi

(Supervisor)

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DEDICATION

This work is dedicated to my wife Mansuratu Omotayo Hassan, Children: Sadiq Hassan, Beverly Agyei Mensah Akrosumah and Abraham Mensah Akrosumah and my late parents: Abraham Agya Mensah and Rosina Akua Donkor, may their souls rest in perfect peace.

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ABSTRACT

This study investigated students' mental models of chemical reactions and balancing chemical equations at Diamono Senior High School in the Brong Ahafo region of Ghana. The study employed case study design using Action Research approach. An intact class of form 2 science class made up of 24 males and 6 female students' were used for the study. The data for this study were derived from class exercises done by students to probe their mental models of chemical reactions and balancing chemical equations for various chemical phenomena. Data collected from the study was analysed qualitatively. Thematic analysis of the students' discourse of their mental models revealed different types of mental models; named Model A, B, and C. Model A was considered as an initial mental model, which was based on students' experience with changes of matter in their daily life. Model B was based either on the attributes related to the kinetic theory of particles or attributes related to chemical bonding. Model C was based on students' scientific ideas but include some erroneous assumptions. A general conclusion drawn from this study was that, some students' mental models were found to be lacking in attributes that relate to scientific ideas such as particle model, particle collisions, activation energy and entropy, despite being introduced with these ideas in their formal learning. It is suggested that students' should be introduced to model-based instruction that encourages them to construct acceptable mental models of particles and link these models with the chemical phenomena. Therefore, an inquiry that investigates the impact of an intervention would be beneficial.

CHAPTER ONE

INTRODUCTION

1.1 Overview

This chapter discusses the background to the study, stating clearly what the Researcher wants to investigate, highlighting on related literature in the area of study such as types of chemical reactions and students' conception and understanding of chemical reactions. The next sub-heading discussed under this chapter is the statement of the problem which highlights the rationale for the study. It also deals with purpose of the study, objectives, and research questions the Researcher wants to answer at the end of the study. Furthermore, the chapter looks at the significance of the study to the various stakeholders in education, limitations, delimitations or peculiar considerations that defined the scope of the study.

1.2 Background to the study

Various research works Herga (2014); Gkitzia (2011); Guzel & Adadan (2013); Jaber & Boujaoude (2012) on mental models have shown that learning with a variety of representations is very important. To enhance the students' understanding of science, especially the use of visualisation representations to explain the phenomenon of sub-micro phenomena. Learning science, particularly chemistry, is more than just developing models of atoms and the literature suggests that students' struggle to understand many scientific concepts. Thus, some research works Duit (2009) and Vosniadou (2012) have been done to find ways that helps students' learn science particularly chemical phenomena. The difficulty of learning science is echoed in the Researcher's own experience when introducing Diamono Senior High School students' to chemical reactions and balancing chemical equations. The Researcher realised that students' were unable to relate the fundamental ideas learnt in their previous lessons to chemical reactions. There are now a vast number of studies reporting various approaches to addressing students' alternative conceptions in chemistry (Barke, Al Hazari, & Yitbarek, 2009; Barker 2000). The gap identified in some of these studies which when resolved would help students' to learn science and rid themselves of alternate conceptions appear to be the use of students' mental models. The Researcher, was, thus, motivated by the advantages enumerated by the literature on the use of mental models to use this approach in an Action Research. This will enable the use of a teaching intervention to facilitate the change in some of the alternate conceptions of students' in some chemistry topics.

1.3 Statement of the Problem

Teaching is a constantly evolving practice where research and studies are being undertaken to find the best practices. The Researcher has observed that Integrated Science and Chemistry students' in the senior high schools in Ghana appear to be unable to answer questions when it comes to chemical reactions and balancing of chemical equations correctly. Most of their wrong answers revealed specific misconceptions which might be from their preconceptions about the topics. Such misconceptions if left uncorrected might affect them in future higher studies in the sciences. However, literature suggests the use of mental models to clear such misconceptions since they make learning more realistic for students' who are in the process of scientific concept formation. Mental models can be regarded as the products of learning (Henderson & Tallman, 2006). It is reported that mental models play important roles in the process of learning because learning generally can be viewed as mental modelling. Thus, mental models are considered important in learning science since it is assumed that they provide valuable information about students' science conceptual frameworks, or underlying knowledge structures (Coll, 2005). Therefore, capturing students' mental models is one way to understand the content and structure of students' knowledge of scientific reasoning as well as reflecting students' beliefs and interpretation of a phenomenon. Hence, mental models appear to hold great promises of making science learning much more authentic to students' in science.

1.4 purpose of the study

The purpose of this study is to explore the nature of students' mental models of chemical reactions and balancing of chemical equations with a view to identifying some of the misconceptions they hold. Then a teaching intervention would be provided to facilitate the correction of the misconceptions.

1.5 Objectives of the Study

The objectives of this study were:

1. to determine the types of alternate conceptions students' have about chemical reactions and balancing of chemical equations
2. to classify the alternate conceptions that students' hold
3. to design a teaching intervention to teach students' some topics like chemical reactions and balancing of chemical equations
4. to determine the influence of the teaching intervention on students' learning outcomes

1.6 Research Questions

In view of the objectives enumerated above, the following research questions were addressed;

1. how would the determinations of the types of alternate conceptions improves students' understanding of chemical phenomena?

2. how can the classification of students' alternate conceptions help them to understand the concept of chemical reactions?
3. how would the design of a teaching intervention help students' to understand concepts in chemistry?
4. how would the teaching intervention influence students' learning outcomes?

1.7 Significance of the Study

Most of the literature on students' understanding of chemical reactions and balancing of chemical equations concentrates on students' conceptions about the conservation of mass, equilibrium, kinetics or thermodynamics – each area typically investigated in isolation in the alternative conceptions research (Fensham, 2001). In order to develop successful teaching approaches to transformations of matter, we need to know more about how young students' develop an understanding of these processes (Lofgren & Hellden, 2008). The present study thus, has the potential to contribute to the literature about our understanding of students' mental models of chemical reactions and balancing of chemical equations as a whole from conservation of mass through to thermodynamics. It also seeks to identify the type of alternate conceptions students' have about chemical reactions. Furthermore, it is hoped that this work will inform science, particularly chemistry educators across educational levels in Ghana and worldwide about the nature and attributes of students' mental models for chemical reactions, and help in the design of teaching intervention to prepare students' for the real world of chemistry.

Additionally, research on students' mental models about chemical reactions would expand chemistry education research, shifting away from previous isolated focus on students' conception of atomic structure and chemical bonding. It is also expected that the difficulties of students' that might be uncovered in this study would make teachers, curriculum developers and science textbook writers think about some innovative ideas on how to help students' understand the concept of chemical reaction and to balance chemical equations correctly. The study would also help students' to balance chemical equations correctly by using chemical models. Like any other research, the findings of the study would serve as the basis for other future research works.

1.8 Limitations of the study

Simon & Goes (2013) points out that limitation are potential weaknesses in research study and are out of the Researcher's control. They limit the extensity to which a study can go, and sometimes affect the end results and conclusions that can be drawn. They are the shortcomings, conditions or influences that cannot be controlled by the Researcher that place restrictions on the methodology and conclusions. Dusick (2011) points out that any assumption the Researcher makes becomes a limitation. Since assumptions are inevitable in empirical studies, the study had some unavoidable limitations. The following limitations can be observed regarding this study:

This study was to cover the entire nation but due to financial constraint and time, the Researcher limited himself to a senior high school (Diamono SHS) in Duadaso N$^{\underline{O}}$2 township. Due to confinement of the research in Duadaso N$^{\underline{O}}$2 township, it might not be proper to generalise the results. The study also involves students', and there was the tendency for these respondents' to give responses which were not the true reflection of the actual situation. This might affect the results of the research.

It was assumed that the population is homogenous in character; hence the sample size was not very large. If this assumption was wrong, then data might not effectively present a large population, and consequently, generalisation of the findings over a large population would be inappropriate. Another limitation was related to the absenteeism on the part of some of the students'. Some students' absented themselves from school due to truancy at the time of intervention and this might introduce error and the results of the study would be affected.

1.9 Delimitations of the study

Dusick (2011) stated that delimitations are characteristics that arise from limitations in a study (defining the boundaries) and by the conscious exclusionary and inclusionary decisions made during the development of the study plan. He further explained that it involves delineating properly the boundaries of the study that is, what will be covered and what will not be covered in the study. It is a way of trying to bring the problem into sharp focus. Setting delimitations and subsequent justifications help the Researcher to maintain objectivity in the study. It also helps other researchers reconstruct a study or advance future research on the topic. Delimitation provides the scope within which researchers conclude their findings and determine a study's reliability or external validity. The delimitations are under the control of the Researcher. Delimiting factors include the choice of objectives, the research questions, variables of interest, theoretical perspectives the Researcher adopted and the population (Simon & Goes, 2013). In the light of the above, the following are the delimitations of the study:

The study was restricted to Diamono Senior High School in the Brong Ahafo Region of Ghana. This was due to proximity and accessibility of the research subjects and also as a teacher in the school. The study was also restricted to SHS 2 students' because adequate time is needed to prepare them and monitor their performance with time before they write the final examination. Finally, the topic chemical reactions and balancing of chemical equations is in their syllabus, which needs to be treated before they write their final examination, West African Senior School Certificate Examination (WASSCE).

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

This chapter provides a review of students' learning in science, and theoretical consideration of the nature of students' learning in science. It begins with an introduction to students' conceptions of scientific knowledge and a discussion of the nature of students' alternative conceptions. This account is followed by a description of students' conceptions or ideas related to different aspects of chemical reactions. It also talks about some theoretical views of students' conception of scientific concepts. Furthermore, the chapter looks at models in science and science education by describing models in terms of their structure and role as a form of representation. This section also includes the typologies of models and the role of models in science. Next, the notion of mental models is described followed by discussion of students' mental models of scientific ideas. The chapter concludes with the roles of models and modelling in the teaching and learning of school science.

2.2 Theoretical Perspectives of Learning Science

Historically, learning science has been seen as transfer of facts from teacher to student – a transmission view of learning based on behaviourism (Allen, 2010). The basic principle of behaviourism is that learning science is a behavioural change induced by stimuli, reinforcement, and punishment, which emphasised science as a collection of facts that need to be memorised, reinforced, and practiced. In other words, a student is considered to be a knowledge recipient from an external source (Collins, 2002). However, the behaviourist view of learning science has been criticised for being limited in explaining and taking into account the phenomena of students' alternative conceptions of scientific ideas when considering how students' learn science (Allen, 2010). This criticism suggests that students' learning of scientific ideas is more than just absorption of knowledge, but rather a process through which they construct their own ideas. Helping students' engage in the process may be enlightened from a constructivist and sociocultural theory of learning science.

2.2.1 Constructivism Views on Learning Science

Although studies of students' alternative conception in science education were not originally based on constructivism, a constructivist view of knowledge is considered an important and influential framework for making sense of science learning in schools (Prawat, 2008; Taber, 2006). The core tenet of constructivism is that knowledge is not transmitted from one person to another, but rather actively constructed in the mind of the learner. Therefore, learners are no longer to be perceived as passive recipients of knowledge, but rather actively interacting with the knowledge to make sense of it. This view implies that students' alternative conceptions may be the result of or be an artefact of classroom teaching.

2.2.2 Sociocultural Perspective of Learning Science

Constructivism seems to have given an in-depth understanding to science educators about students' learning, and constructivism's main assertion is that learning requires construction of knowledge by a cognising being. This notion somewhat contradicts more traditional views of learning, which typically portray students' as rather passive recipients of knowledge. However, neither constructivism nor traditional teaching provides an adequate vehicle for students' learning. That is, whilst students' are more than passive receivers of knowledge, when taught via a constructivist-based pedagogy, they are still often found to develop alternative conceptions (Kozulin, 2003). Scientists all over the world commented that for science education to be effective, it must take much more explicit account of the cultural context of the society which provides its setting including the economic, political, social, religious, philosophical, and language context. The fundamental tenet of this theory is that the human inner mental processes ought to be understood through an appreciation of their sociocultural context or background (Van der Veer, 2007). This can be conceptualised around the concepts of mediation, psychological tools, and the zone of proximal development (ZPD) (Kozulin, 2003). The zone of proximal development can be seen as a learning potential in terms of the psychological functions of an individual that are emerging and have not yet fully developed or matured (Chaiklin, 2003; Kozulin, 2003). It is assumed that interaction within the zone, between a more competent and less competent learner, results in the less competent person human becoming more proficient compared to their initial competence (Chaiklin, 2003). So if, a child has already developed adequate mental function, he or she will be able to develop further competency through interaction or collaboration with a more knowledgeable other, typically a teacher. Scientific concepts, in turn, supply structures for the upward development of the child's spontaneous concepts toward consciousness and deliberate use. Spontaneous concepts and scientific concepts may differ greatly, but both are crucial in the development of children’s minds. These spontaneous concepts provide affordance for the acquisition of scientific concepts and once the scientific concepts have been acquired, they act as everyday life knowledge, meaning that children’s spontaneous concepts have become more structured (Karpov, 2003).

2.3 Students’ Alternative Conceptions in Learning Science

An indication of students’ struggle with the learning of scientific ideas is evident in their considerably different understanding compared with that of the scientific community. Many of these non-scientific ideas are commonly referred to as ***alternative conceptions*** and have been studied intensively by many science educators (e.g., Barke, 2009; Barker, 2000; Duit, 2009). There are various terms used when referring to students' non-scientific ideas other than alternative conceptions; such as naive conceptions, pre-conceptions or children's science. Some authors refer to students' ideas as alternative frameworks. Most importantly, it is argued that alternative conceptions and misconceptions should be viewed differently. Alternative conceptions are used to acknowledge that students' have constructed their own understanding of the concepts under consideration. However, it has been pointed out that misconceptions should be seen as erroneous conceptions, which are clearly inconsistent with accepted conceptions. Here in this study, the term ***alternative conception*** is used to mean students' different conception of scientific ideas regardless of whether these conceptions are entirely erroneous, or partially consistent with the scientific view.

2.3.1 Characteristics of Students' Alternative Conceptions

Students' alternative conceptions are highly dependent on their senses, and often reported that any non-tangible entity is considered not to exist by many students'. Believing that sugar disappears during dissolution and similarly water in the evaporation process Tytler (2000), and that there are no forces acting on stationary objects Stein, Larrabee, & Barman (2008) are some examples of such thinking. Additionally, students' alternative conceptions are reported to be personalised, in that students' are thought to construct their own individual meaning or interpretation of any kind of experience including scientific phenomena. A feature of students' personalisation of their alternative conceptions is their frequent use of everyday language meanings such as, explaining electricity as identical to road traffic flow, chemicals are seen as harmful substances Cavallo, McNeely, & Marek (2003), and particles as minute, visible solids instead of atoms, ions or molecules. Besides the use of everyday language, students' alternative conceptions are also tended to be anthropocentric. For example, they associate their conceptions with human nature when describing scientific phenomena, saying things like "atoms wanted or needed to gain or lose electrons," or "the atom enjoys forming a compound". Therefore, it seems that students' alternative conceptions are often context-dependent. Given that students' alternative conceptions are often personalised and anthropomorphic, alternative conceptions can be argued to be unreal in nature, meaning that instead of discarding their preconceptions, students' are assimilating or fusing their preconceptions with the formal knowledge introduced in school (Vosniadou, 2012). For example, young children presumably perceive Earth as a hollow sphere with flat ground on it where the living things are – *a combination of the preconceived idea of a flat Earth, with the scientific view of a spherical Earth.* Although, alternative conceptions appear to be context-dependent and unplanned or spontaneous in nature by being personalised, anthropomorphic and materialised, the literature consistently asserts that students' alternative conceptions are stable, tenacious and highly resistant to change by conventional instruction (Vosniadou, 2012). This stability of alternative conceptions probably occurs because they are actually coherent and theory like, at least from the students' point of view (Vosniadou, 2012). Nevertheless, in some cases, students' alternative conceptions are changeable, but this depends on the complexity of the scientific concepts encountered by students (Chi, 2005). There are also a variety of research reports that certain alternative conceptions diminish as students' age (Paik, Choo, & Go, 2007).

2.3.2 Students' Conceptions as Implicit Knowledge

Despite the recognition of the importance of students' alternative conceptions in science education, the almost unending directory of alternative conceptions from various areas of science does not seem to offer any indications as to how we might draw upon this knowledge and enhance the teaching and learning of science (Talanquer, 2002, 2006). Although this approach has been invaluable information to chemistry teachers, it fails to explain the origins or nature of the full range of alternative ideas especially in the chemistry domain, where studies have heavily concentrated on the explicit aspect of students' conceptions (Taber & García-Franco, 2010). It is clear that students' explanations about chemical phenomena and other scientific ideas are based on common sources including everyday life experiences. There is some evidence that alternative conceptions reported are rooted in students' intuitive and implicit knowledge (Maeyer & Talanquer, 2010; McClary & Talanquer, 2011; Talanquer, 2002, 2006; Viennot, 2001). This knowledge is referred to using a variety of labels, and studied in a variety of ways including implicit assumptions, heuristics (Talanquer, 2002, 2006). The literature refers to this type of knowledge in numerous labels such as common sense (Talanquer, 2006; Viennot, 2001), cognitive constraints (Maeyer & Talanquer, 2010), preconscious cognitive elements (McClary & Talanquer, 2011), and implicit knowledge elements (Taber & García-Franco, 2010). One component of senior high school students' intuitive knowledge in the chemistry domain is that students' think that chemical substances have underlying qualities or inherent essences that contribute to the properties of the chemical substances (Taber & García-Franco, 2010; Talanquer, 2006). Consequently, based on this intuitive knowledge, students' perceive chemical reactions as mere changes of the inherent components of matter, without any changes happening in the chemical structures of the substances, that is, the components changed but not the substances. Besides assigning properties of materials to inherent components, senior high school students' are also found intuitively to consider the properties of substances as inherently natural (Taber & García-Franco, 2010). For example, a chemical reaction happens because it is thought to be natural for substances to react with each other, and so no further explanations are required. Intuitively, students' like other human beings, seem to think that events happen or are caused by certain external agents or factors. This thinking is referred to as the causality intuition**,** which is considered to be the most common intuition to be found in any of the science disciplines (Bliss, 2008; Taber & García-Franco, 2010; Talanquer, 2006, 2010; Viennot, 2001). Examples of chemistry alternative conceptions related to the causality notion include: *the view of chemical reactions occurring as the result of more reactive reactants* (Boo & Watson, 2001); *heat energy or flame as an agent for change of substances* (Taber & García-Franco, 2010) and *chemical reactions occurring as the result of various actions toward chemical substances by external agents such as other chemical substances, surroundings, and human interventions* (Hatzinikita, Koulaidis,& Hatzinikitas, 2005).

2.4 Students' Conceptions about Chemical Reactions

Various studies have indicated that the idea of chemical reactions is considered difficult by many students' (Johnson, 2002; Papageorgiou, Grammaticopoulou, & Johnson, 2010). A common difficulty reported in the literature is the identification of chemical reactions, or differentiating chemical reactions from physical changes (Eilks, 2007; Palmer, 2006). A study reported that 20% of Finnish students' viewed dissolving and changing of physical state as chemical reactions. While in other work, there is evidence that students', especially senior high students, are not readily able to identify burning as a chemical reaction. For instance, American secondary and university students' were reported to consider the burning of a candle as melting, and New Zealand secondary students' thought that heating sugar until it changed into a brown frothy liquid giving off visible fumes was melting. This difficulty in differentiating chemical reactions and physical changes is a major problem to most senior high school students' in Ghana and worldwide. Students' confusion is also observed when terms related to physical change such as melting, change of physical state and evaporation are used in describing chemical reactions. The literature indicates that although students' recognise that changes happen in chemical reactions, they are not necessarily aware of the formation of new substance(s). Chemical reactions are perceived by these students' as a process of mixing of substances or changes in physical characteristics, that is morphological modification such as change in shape, texture, and colour, whereby the initial substance(s) is/are thought to be unchanged. Students' views of transformations of matter as a modification or displacement process probably arise due to confusion between chemical reactions and physical changes as mentioned earlier. Students' displacement and modification ideas often coincide with physical change explanations. Johnson (2000) argued that such explanations of chemical reactions may indicate that students' are unwilling to accept that products in chemical reactions are actually new substances produced from the initial substance(s). Even though students' may recognise that in chemical reactions, the initial substances undergo changes and new substances are formed. Their explanations of chemical phenomena are rarely based on the scientific view, and deviate from what scientists understand.

2.5 Types of Chemical Reactions

A chemical reaction is a process that leads to the transformation of one set of chemical substances to another. Chemical reaction can be either **spontaneous**; requiring no input of energy or **non-spontaneous**, typically following the input of some type of energy viz heat, light or electricity. A chemical equation is the symbolic representation of a chemical reaction in the form of symbols and formulae. Chemical equation is a statement involving formulas that express the identities and quantities of the substances involved in a chemical or physical change. The left side of an equation shows the amount of each substance present before the change (**Reactant**), and the right side shows the amounts present afterward (**Product**).

In chemical reaction, all the substances that react during the change are called ***reactants***, and they are placed to the left of the yield arrow, which points to all the substances produced, called ***products***. That is:

$$\mathbf{A + B \longrightarrow AB}$$

(Reactants) (Product)

A coefficient is a number placed before a formula in a balanced chemical equation to indicate the relative amount of substances represented by the formula. For example;

$$\mathbf{2H_2 + O_2 \longrightarrow 2H_2O}$$

The numbers 2, 1 and 2 placed before the H_2, O_2 and H_2O are the coefficients of H_2, O_2 and H_2O in the equation respectively.

All chemical reactions can be placed into one of the six (6) categories of chemical reactions. The six major types of chemical reactions are discussed below:

2.5.1 Direct combination (synthesis reaction)

In the synthesis reaction, two or more chemical species combine to form a more complex product. Any reaction in which two or more substances combine to form a single product is a direct union or combination reaction. The general form of a direct union reaction is:

$$\mathbf{A + B \rightarrow AB}$$

This type of reaction generally takes place between the following types of compounds:

1. A metal + non-metal

$$\mathbf{2Na + Cl_2 \rightarrow 2NaCl} \text{ (Sodium chloride)}$$

2. Metal oxide + non-metal oxide

$$\mathbf{CaO + CO_2 \rightarrow CaCO_3} \text{ (Calcium carbonate)}$$

3. Non-metal + non-metal

$$\mathbf{C + O_2 \rightarrow CO_2} \text{ (Carbon (II) oxide)}$$

2.5.2 Chemical decomposition (analysis reaction)

In a decomposition reaction, a compound is broken into smaller chemical species. Decomposition is the reverse of combination. That is, a single reactant is broken down into two or more products either elements or compounds. A decomposition reaction will take place because the compound is *unstable* or *as a result of heating or electrical decomposition (electrolysis).* The general form for a decomposition reaction is: $\mathbf{AB \rightarrow A + B}$

Some examples of decomposition reactions are:

1. the electrolysis of water into Oxygen and hydrogen gas

$$2H_2O_{(l)} \rightarrow 2H_2 + O_2$$

2. the decomposition of calcium carbonate into calcium oxide and carbon dioxide

$$CaCO_3 \rightarrow CaO + CO_2$$

2.5.3 Substitution Reaction (Single Displacement)

A substitution reaction is characterised by one element being displaced from a compound by another element. 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 reaction is:

$$A+BC \rightarrow AC+B$$

Displacement reactions usually occur between the following combinations:

1. An active metal + an acid

$$Zn+2HCl \rightarrow ZnCl+H_2$$

2. A metal + a salt

$$Fe + CuSO_4 \rightarrow FeSO_4 + Cu$$

3. A Halogen + halide salt

$$Cl_2 + 2NaI \rightarrow 2NaCl + I_2$$

2.5.4 Double Displacement (metathesis)

A metathesis is a double displacement reaction that usually occurs in water solution. In this type of reaction, two compounds exchange bonds or ion in order to form different compounds. The general form of a metathesis reaction is:

$$AB + CD \rightarrow AD + CB$$

An example of a double displacement reaction occurs between sodium chloride and silver nitrate to form sodium nitrate and silver chloride.

$$\mathbf{NaCl_{(aq)} + AgNO_{3(aq)} \rightarrow NaNo_{3(aq)} + AgCl_{(s)}.}$$

2.5.5 Neutralization reaction (acid-base reaction)

An acid-base reaction is a type of double displacement reaction that occurs between an acid and a base. a neutralization reaction occurs between an acidic compound and a basic compound to form a chemical salt and water. The H^+ ion in the acid reacts with the OH^- ion in the base to form an ionic salt and water.

$$\mathbf{HA+BOH \rightarrow BA+H_2O}$$

The reaction between hydrochloric acid (HCl) and sodium hydroxide (NaOH) is an example of neutralization reaction.

$$\mathbf{HCl + NaOH \rightarrow NaCl + H_2O}$$

2.5.6 Oxidation-Reduction (Redox reaction)

Redox reaction may involve the transfer of electrons between chemical species. In a redox reaction, the oxidation numbers of atoms are changed. The reaction that occurs when I_2 is reduced to I^- and $S_2O_3^{2-}$ (thiosulphate anion) is oxidized to $S_4O_6^{2-}$ provides an example of a redox reaction.

2.6 Students' Understanding of Chemical Reactions

Chemistry educators have often observed that learning chemistry is particularly difficult at any level of education. A factor that may contribute to the difficulties in learning chemistry may be due to the complexity nature of concepts used in chemistry, as in other sciences, that are abstract in nature, and they are usually presented to students' using a variety of models.

Besides that, the models used in the representation of chemistry concepts cover at least three different levels of chemistry – ***macro, submicro and symbolic***. These difficulties in learning chemistry as well as other science areas are not because of these levels of representation, but rather the demands that incurred in understanding them simultaneously. Therefore, the complex nature of chemistry can lead to various student difficulties for even the most fundamental ideas of chemistry, such as chemical reactions.

2.6.1 Students' Understanding of Direct combination (synthesis reaction)

In the synthesis reaction, two or more chemical species combine to form a more complex product. A single substance as a product is the key characteristic of the synthesis reaction.

The Researcher, when introducing this type of chemical reaction to the students', the students' were confused about the composition of water. ''Water is composed of hydrogen and oxygen''. Students' often hears these or similar statements in classrooms about compounds, which supposedly ''contain'' certain elements. These expressions arise from a time when it was common to analyse and find out which elements make up certain compounds.

Students' associated the substances, copper and sulphur in the black copper sulphide, particularly as experiments shows that one can remove these elements out of copper sulphide. Most of the students' did not understand why the metal sulphides could be produced from metals and sulphur. The students' lack the idea about ''atoms'' and ''ions'' as the smallest particles of matter. Because of this, they cannot expand on these statements, that the compound ''contains'' special atoms or ions, that one water molecule contains two H atoms and one O atom connected and arranged in a particular spatial structure.

2.6.2 Students' Understanding of Chemical Decomposition (Analysis reaction)

In a decomposition reaction, a compound is broken into smaller chemical species. That is, a single reactant is broken down into two or more products either elements or compounds (David, 2004). According to Taber (2000), students' explanations have largely been considered as data collected as evidence of students' conceptualisations of science topics. His research discusses the difference between a student's response to a question, a student's alternative conceptions, and a student's explanation. Students' often use descriptions and over-generalisations instead of explanations in order to rationalise phenomena. The Researchers students' could identify the reaction for the oxidation of iron written in formulas as a synthesis or addition reaction; but when confronted with a written scenario, a large portion of the students' identified that same situation as a decomposition reaction. The responses the Researcher received from the students' led him to the inclination that many of the students had some poorly defined conceptual frameworks.

2.6.3 Students' Understanding of Substitution Reaction (Single Displacement)

According to Ball (2011), a single-replacement reaction is a chemical reaction in which one element is substituted for another element in a compound, generating a new element and a new compound as products. A typical characteristic of a single-replacement reaction is that there is one element as a reactant and another element as a product. Students' often confused this type of reaction as far as halogens (fluorine, chlorine, bromine, and iodine) are concerned. The halogens are the elements in the next-to-last column on the periodic table. Students' became confused about how the elements on top of the column will replace the elements below it on the periodic table but not the other way around. For example, the reaction;

$CaI_{2(s)} + Cl_{2(g)} \rightarrow CaCl_{2(s)} + I_{2(s)}$ will occur, but the reaction

$CaF_{2(s)} + Br_{2(\ell)} \rightarrow CaBr_{2(s)} + F_{2(g)}$ will not because bromine is below fluorine on the periodic table. Students' also do not understand the activity series on the periodic table as there are so many elements that can form cations; an element in one column on the periodic table may replace another element nearby, or it may not. They were confused about how an element on top will replace an element below it in compounds undergoing a single-replacement reaction whiles elements will not replace elements above them in compounds. Students' were given two chemical equations to predict the products as in single replacement reaction as shown below;

1. $FeCl_2 + Zn \rightarrow ?$

2. $HNO_3 + Au \rightarrow ?$

Majority of the students' were not able to write the products. When asked, they said they thought they could do it without considering the activity series on the periodic table. The second equation especially, they predicted the product as $AuNO_3$ forgetting that Gold is below hydrogen in the activity series. As such, it will not replace hydrogen in a compound with the nitrate ion.

2.6.4 Students' Understanding of Double Displacement reaction (metathesis)

A double-replacement reaction occurs when parts of two ionic compounds are exchanged, making two new compounds (Ball, 2011). A characteristic of a double-replacement equation is that there are two compounds as reactants and two different compounds as products. There are two equivalent ways of considering a double-replacement equation: either the cations are swapped, or the anions are swapped. You cannot swap both; you would end up with the same substances you started with. This means that we pair a cation with an anion and not a cation with a cation or an anion with an anion (Ball, 2011). Students' always pair cation with a cation or an anion with an anion. So they often end up with the same reactants. When asked about cations and anions, they could not explain the two terms.

2.6.5 Students' Understanding of Neutralisation reaction (Acid-base reaction)

A neutralisation reaction occurs between an acidic compound and a basic compound to form a chemical salt and water. The H^+ ion in the acid reacts with the OH^- ion in the base to form an ionic salt and water (David, 2004). When students' were asked about the neutralisation reaction, they responded that a salt solution appeared in neutralisation. Most of the students' thought that neutralisation reaction has a PH of 7(neutral) as the name implies. Students' idea that every neutralisation yields a neutral solution is hence a misconception. Students' also had it in their minds that in neutralisation, the alkali breaks down the acid and stops the acid from "working", Only acids are corrosive, bases are not. According to Schmidt (2000), the basic teaching of neutralisation can lead students to believe, initially, that all salts are neutral. That is: Acid + Base = Water + Salt, as the example most often given is HCl and NaOH, which does provide a neutral salt when reacted together. Students' thought that, in neutralisation reaction, only common salt (sodium chloride) is formed. When students' were introduced to the idea that an acid and base reaction can make an acidic or basic salt, they became confused.

2.6.6 Students' Understanding of Redox reaction (Oxidation-Reduction reaction)

A chemical reaction that involves the transfer of electrons (Ball, 2011). In a redox reaction, the oxidation numbers of atoms are changed. Students' always become confused when they hear gain of electrons or loss of electrons as in reduction and oxidation reactions. They wander why both oxidation and reduction reactions always occur together; it is only mentally that we can separate them. Most students' could not determine which element loses or gains an electron and could not assign oxidation numbers to elements. They perceived all halogens to have positive charges. When students' heard elements like fluorine is assigned a −1 oxidation number whiles in binary compounds with fluorine, oxidation is positive, they became confused. They also perceived hydrogen to have positive oxidation number in any form (Ball, 2011). So when they were introduced to hydrogen having a negative oxidation number when it is in the form of metal hydride, Ball (2011), they found it difficult to grasp that concept. Students' also had it in their mind that there is no increase or decrease in oxidation numbers. So when they heard that, when an oxidation number of an atom is increased in the course of a redox reaction, that atom is being *oxidized* and when an oxidation number of an atom is decreased in the course of a redox reaction, that atom is being *reduced*. This statement was in contrast to their initial idea about redox reactions. Students' idea of a redox reaction is, therefore, a misconception or alternative conception that is not on the same level with a scientific concept.

2.7 Chemical Reactions at the Particulate Level

It seems from various literature, students' views about the process of chemical reactions or the transformations of matter at the submicro level are little understood. American high school students', even though exposed to kinetic ideas in chemical and physical change, fail to invoke the particulate nature of matter when explaining the rusting of an iron, nail, the oxidation of copper metal, and the burning of a wood splint. Similarly, in a longitudinal study, Löfgren & Helldén (2008, 2009) conducted a series of interventions introducing the idea of particulate nature of matter. However, they found that only a fifth of the Swedish students' at the age of 16 were able to use the submicro ideas in explaining the phenomena of fading leaves left lying on the ground, disappearance of the wax of a burning candle, and the appearance of mist on the inside cover of a glass of water. When students' do attempt to apply the idea of the particulate nature of matter in explaining chemical reactions at the submicro level, their views about the process of chemical reactions are often different from the scientific model. These students' believe that the characteristics of the macro level are transferred into the submicro level, and this conception is referred to as ***'continuity'*** (Talanquer, 2006). This belief is also similar to those of students' who think that particles from the initial substances are combined to form new types of particles (Eilks, 2007). However, the literature suggests that students' have their own views of chemical reactions at the submicro level. However, there is little work concerning students' understanding on what happens to the initial particles during chemical reactions.

2.8. Students' mental models of chemical equations

Equations are essential tools to communicate chemical reactions at macroscopic, submicroscopic and representational levels of understanding chemistry. Just as secretaries use shorthand to take down dictation, chemists use shorthand to show changes that take place during a chemical change. A chemical equation is a shorthand description of a chemical reaction, using symbols and formulas to represent the elements and compounds involved (Prenhall, 2005). A chemical equation represents a chemical reaction. Chemical equations are used to graphically illustrate chemical reactions (Myers, 2009). It consists of chemical or structural formulas of the **reactants** on the left and those of the **products** on the right. It is separated by an **arrow** (→) which indicates the direction and type of the reaction. The arrow is read as the word "yields". The tip of the arrow points in the direction in which the reaction proceeds (Myers, 2009). The chemical equation is a language of chemistry, one that chemists and chemical educators use constantly (Mulford & Robinson, 2002). Once chemical equations have been introduced in a course of study, it is often assumed that students' understand this representational system. But many of the difficulties in learning chemistry are related to chemical equations (Mulford & Robinson, 2002). If students' do not understand the language used by the instructor, how can they be expected to understand what is said? (Mulford & Robinson, 2002). Experience and literature show that most high school students' do not have the correct mental models of coefficients and subscripts in chemical reactions. They seemed unable to use the information contained in the coefficients and subscripts to construct the individual molecules. One barrier to understanding chemical equations is confusion over the symbols, especially subscripts and coefficients (Austin & Jeffery, 2004). For instance, when asked to state the difference between O_2 (the diatomic form of oxygen) and 2O (two atoms of oxygen), many students' say the two are identical. Students' may have difficulty with coefficients and subscripts because both are abstract concepts that are not easy to visualise (Austin & Jeffery, 2004). Students' were able to use formulas in chemical equations correctly without understanding the meaning of the formula in terms of particles that the symbols represent. Many chemical equations also include phase labels for the substances: (s) for solid, (ℓ) for liquid, (g) for gas and (aq) for aqueous (Ball, 2011). Most students' do not know which reactants and products should be assigned with these phase labels for substances as stated in (Ball, 2011). In many classrooms, students' are taught to tackle word problems with specific algorithms for each problem type, and they often develop a reliance on cookie-cutter equations without fully comprehending the underlying problem and the algebra used to solve it(Michelle, 2004). Many students' find it difficult to write or complete word equations for chemical reactions. This should not be surprising if it is remembered that although chemical names seem familiar to teachers (with many years of acquaintance using them) they may seem somewhat arbitrary to students'. One science educator has told me how in school, he spent two years perplexed at why chlorides should be produced in reactions of 'hydrochloric acid. The more systematic names, such as tetraoxosulphate (VI) for the SO^{2-} ion, may be especially difficult for students'. According to Schmidt (2000) if the names do not seem to fit an accessible pattern, then students' may well be concerned about the very large number of substances they could hear and read about. Students' were given Magnesium Oxide and Sodium Chloride to write the proper chemical equation. Results indicated that most of the students' were able to answer the question at a macroscopic, microscopic and symbolic level for magnesium oxide and sodium chloride. Most of them were capable of explaining both compounds and their given answers are relatively aligned with the scientific concept. However, the majority of them failed to write an appropriate chemical equation to show the formation of MgO and NaCl. Two mistakes were identified: *that they were not able to write a balanced chemical equation* and *they did not know how to differentiate between chemical equations and chemical formulae*. This is relevant to the findings of a study by Hafilah (2008) that stated the students' difficulties in applying the chemical equations, chemical formulae and ionic equations when they were asked to explain the formation of a compound.

2.8.1 Students' mental models of balancing chemical equations

A balanced chemical equation is an equation on which the total number of atoms of each element of the left hand side is equal to the total number of the same atoms on the right hand side (Viraf, 2008). Balancing the equation is done by placing the correct number of moles before the symbols or formulae of the substance such that atoms are conserve. Many students' struggle with balancing equations because they do not understand the concepts behind the process (Austin & Jeffery, 2004). Other students' appear to have mastered balancing, but testing shows they are solving the problems through a rote process. For these students', balancing chemical equations is like balancing an account ledger or solving for a variable in an algebra problem, and they ultimately do not comprehend the reasons for balancing chemical reactions (Austin & Jeffery, 2004). In balancing equations, it is important to understand the difference between a coefficient of a formula and a subscript in a formula. Stoichiometric coefficients are numbers placed in front of formulas in a chemical equation to balance the equation. It indicates the combining ratios of the reactants and the ratios in which products are formed (Viraf, 2008). The coefficients in a balanced chemical equation can be interpreted both as the relative number of molecules, moles or formula units involved in the reaction. Subscripts on the other hand, indicate the relative number of atoms in a chemical formula. Subscripts should never be changed in balancing an equation, because changing subscript changes the identity of the substance. In contrast, changing a coefficient in a formula changes only the amount and not the identity of the substance and hence can be manipulated in balancing chemical equations (Sileshi, 2011). Most students' often try to change both subscripts and coefficients when balancing chemical equations. Students' were able to use formulas in equations and even balance equations correctly without understanding the meaning of the formula in terms of particles that the symbols represent. These students' had an additive view of chemical reactions rather than an interactive one. Students' may have difficulties in understanding the meaning of formula subscripts and equation coefficients. For instance, students' tend to change the subscripts while balancing reaction equations (Johnson, 2000).

Students' may consider balancing chemical reactions as mainly mathematical manipulations of symbols without much insight in the chemical meaning. For instance, students' may consider $3H_2$ as six linked atoms (Johnson, 2000). One barrier to understanding chemical equations is confusion over the symbols, especially subscripts and coefficients.

Students' may have difficulty with coefficients and subscripts because both are abstract concepts that are not easy to visualise (Austin & Jeffery, 2004). These students' lack the idea of the law of conservation of mass, which states that the quantity of each element does not change in a chemical reaction. Thus, each side of the chemical equation must represent the same quantity of any particular element. Many students' perceive the balancing of equations as a strictly algorithmic (plug-and-chug). Most students' had it in their minds that all coefficients are whole numbers. So when it comes to fractional coefficients, they find it difficult to grasp that concept by multiplying every coefficient with a common number to make them whole, typically the denominator of the fractional coefficient for a reaction with a single fractional coefficient. Students' cannot appreciate the fact that balancing a chemical equations was analogous to simple algebra in Mathematics and that the stoichiometric co-efficient in a chemical equation were equal to the co-efficient of the variables in an algebraic expression.

2.9 Conservation of Mass

Another prevalent concern about students' understanding of chemical reactions is related to one of the most fundamental principles – *the conservation of mass*. Although this notion is considered simple by most practicing chemists, it seems that students' struggle to grasp and apply the idea of conservation of mass both in chemical reactions and physical changes (Lajium, 2005; Lay, 2009; Martin, 2008). It is commonly reported that students' almost always have mass-density confusion when predicting mass change in chemical reactions. They thought that solid products such as precipitations increase the mass of a chemical system, since a solid is thought to be heavier than a liquid or gas. For example, about 30% of British advanced level students' indicated that the production of solid precipitate in reactions is responsible for mass increase. Agung & Schwartz (2007) reported that more than a third of Indonesian eleventh-graders (ages 17-19) thought that the formation of precipitate indicates an increase in the total mass of the chemical system. Besides that, another study showed that students' aged between 9 and 14 years think that a water-sugar solution has less mass compared to the initial masses of sugar and water, arguing that the sugar solution is in liquid form, which weighs less than the solid form of sugar. A similar situation occurs in the case of gas formation in a chemical reaction, where a gas is thought to be lighter than a solid or liquid, or does not have mass, leading students' to think of reduction of mass in a chemical system when gas is produced(Agung & Schwartz, 2007). A study suggested that, students' construct intuitive proposition or rules regarding the relation between mass and weight where the physical state of matter in gas and liquid always weigh less than solid.

2.10 Chemical Reactions and Energy

In addition to students' difficulties in constructing an acceptable understanding of the processes mentioned to date in chemical reactions, students' learning about the role of energy in chemical reactions is reported to be an even greater challenge. The abstractness of concepts such as temperature, heat, energy, entropy, spontaneity, endothermic and exothermic, combined with the abstractness of particle concepts makes it even more difficult for students' to develop their mental models of chemical reactions. Some students' at the higher level of education (age >16) fail to relate energy changes with change of chemical bonds (Ebenezer & Fraser, 2001; Greenbowe

& Meltzer, 2003), and these students' are often reported to inaccurately explain the direction of energy transfer in the breaking and formation of chemical bonds in exothermic reactions. These students' tend to think that energy is released when breaking of chemical bonds occurs, and absorbed in the formation of chemical bonds (Barker & Millar, 2000; Boo & Watson, 2001; Ebenezer & Fraser, 2001; Galley, 2004; Yalçınkaya, Taştan, & Boz, 2009). In other words, students' assumed that being exothermic or release of energy is a specific characteristic of chemical reactions (Eilks, 2007; Yalçınkaya, Tastan, & Boz, 2009). Nevertheless, most of the studies mentioned here concentrated on exothermic reactions such as combustion and metal oxidation, with rather less attention being paid to endothermic reactions.

2.11 Tendency of Chemical Reactions to Occur

Although primary school students' may not have been exposed to ideas as to why chemical reactions happen (Taber, 2000). Young students' presented intuitive or in-built explanations of why chemical reactions occur which were anchored in personal ideas (Löfgren & Helldén, 2008). Greek primary school students' (ages 12-13), for example, found to argue that chemical reactions are changes of matter that is induced artificially by either human actions or interventions or from other factors in cause-effect events such as heat, temperature, or condition (*i.e., agents of changes*). Similarly, physical changes were also considered to be natural occurrences by students', where changes occur without influence by agents. Hatzinikita (2005) called this explanation an agentive explanation, where at least one agent or factor is necessary for the production of changes. The agent can be one or both of the chemical substances or other conditions that are responsible for the change happening or cause a substance to undergo changes. Students' at higher levels of education may be able to explain and solve mathematical equations related to entropy, spontaneity and Gibbs energy, but they often fail to invoke their knowledge about chemical thermodynamics when explaining the occurrence of chemical reactions (Boo & Watson, 2001; Sözbilir, 2003; Sözbilir & Bennett, 2007; Teichert & Stacy, 2002). High school and university students' are also commonly reported applying causality reasoning when explaining why chemical reactions occur. They think that chemical reactions involve causal agents. The tendency of chemical reactions to occur is also explained based on the stability experimental or the reasoning, that products are more stable than reactants (Yalçınkaya, 2009). This mode of thinking is similar to what Taber (2009) has coined 'octet thinking,' where his students' thought that chemical species such as ions are more stable than its original atoms when they achieve a stable octet electronic configuration.

The scientific explanation of why chemical reactions occur is based on the Second Law of Thermodynamics, where chemical reactions tend to proceed or are spontaneous when the process results in an increase of entropy of the universe (Atkins, 2005; Zumdahl, 2005). Most senior high school students' could not distinguish between kinetic, heat, and potential energy in a study conducted when teaching SHS 1 students' energy and types of energy. For example, they were confused by the relation between entropy and kinetic energy. This can be testified by the study conducted by Sözbilir & Bennett (2007), and tried to predict the rate of reaction using thermodynamic measures such as the enthalpy, equilibrium constant and Gibbs energy (Cakmakci, 2010; Sözbilir, Pınarbaş, & Canpolat, 2010). Based on these observations, many students' fail to see the holistic nature of chemistry concepts, that is the understanding of how reactions occur, why some reactions are fast or slow, why reactions actually occur, and why some release or absorb energy, despite being exposed to scientific ideas of chemical reactions in the formal education. These findings may be an indication that students' either do not construct mental models of chemical reactions close to the scientific models or do not use them as a tool to understand their everyday experiences.

2.12 Students' perception and attitudes towards Science education

A number of researches have stated that attitudinal measurement could have some relationship with measures of students' interest and achievement in science. Every individual has an inborn ability to learn. The manifestation of these abilities depends on the environmental influence on the individual. Environmental influence includes the effect of the school on the student. Nolen (2003) established that students' perceptions of their science learning, motivation, and achievement, combined with attitudes about the classroom climate, play a significant role in both students' science achievement and accomplishment in learning science. Considering students' perceptions and attitudes is important to opening science learning to all. Wallace, Hand, & Prain, (2004) stated that "science is for all students, not to those who are scientifically talented''. Students' at all stages of development should have opportunities for rich experiences in science, including various forms of scientific writing. If the student is not properly and positively oriented, it affects the development of his or her ability. The student's interest in a particular subject may depend on his or her attitude, motivation, perception and socio-cultural influence. Thus, students' who have positive attitude and perception towards chemical reactions and balancing of chemical equations are more likely to study the subject better than those whose attitude and perception are negative. The attitudinal research is based on the premise that students' meaningful engagement in learning science is primarily determined by their level of motivation and positive attitudes and optimism towards the subject (Osborne, Simon, &Collins, 2011; Rogoff, 2006). The attitude- based research studies conducted by Foley & McPhee (2008); Haussler & Hoffmann (2003) typically have focused on students' attitudes toward learning science. In the attitude-based research, the main focus has been on perceptions, experiences, emotions, thoughts, opinions, enthusiasm, likes and dislikes, and so on. Overview of the various finding from attitudinal research literature can be summarised into three interrelated broad or general principles. First, students' attitude toward science is an important determinant of how students' relate to the subject that in turn influences how they learn science; second, students' attitude toward science is shaped by numerous factors from the sociocultural environment in which students' live and undergo social experiences which in turn influence students' cognitive or intellectual abilities; and third, positive attitude towards science are inherently linked with their social and life experiences and thereby students' level of success in learning science is attributed to the level of motivation they bring to learning the subject (Ali, 2012). These principles, emanating from attitudinal research, have important implications for efforts toward improving science education (Ali, 2012). Research in science education has established that students' level of success in learning science is inherently linked with their positive attitude toward science that in turn is attributed to the level of motivation they bring to learning the subject (Ali, 2012).

2.13 Models in Science and Science Education

Model as a term is omnipresent (Bezivin, 2010). It is used widely in different contexts in life and people understand the word 'model' in different ways other than in science. For instance, we might use it to refer to a representation of something such as buildings, landscapes, and miniature cars. We may also use the term model to refer to a variety of machines, or people who exemplify certain ideals such as fashion models.

Even amongst scholars, use of the term model varies. Therefore, it is worthwhile to examine the nature of models for the use in this study in terms of structure.

2.13.1 The structure of models

Models can be things such as graphs, pictures and formulae, or discourse such as metaphors and actions, or concrete material objects like replicas of buildings (Boulter & Buckley, 2000). Although we use the term differently, all usage comes with the notion of a model representing something for a specific purpose within a well-defined scope (Halloun, 2006). In other words, a model can be generally defined as a representation of a particular *target* such as an object, event, process, idea or system (Gilbert, Boulter, & Elmer, 2000; Oh & Oh, 2011; Shusaku & Bret, 2009). Consider the atomic structure model based on Rutherford's and Bohr's theory, which is used widely in secondary schools. From Rutherford's observation of the scattering experiment (in which alpha particles were used to bombard gold foil), he proposed that the atom has not only electrons as in Thomson's model of the atom, but also a nucleus at the centre (Zumdahl, 2005). At the same time, when explaining the phenomena of light emission and absorption, Bohr postulated that electrons in atoms are arranged in orbits, with definite energy levels (Goldberg, 2007). Therefore, a model of an atom can be constructed to represent the attributes of Rutherford's atom and Bohr's atom by mapping or transferring the attributes of a nucleus and orbiting electron(s), in fixed energy levels, and the Solar System with orbiting planets and the sun at the centre, to the atomic model, which depicts that the electrons rotate around the nucleus in fixed orbits. Tregidgo & Ratcliffe (2000), in science, a model is the outcome of representing an object, phenomenon or idea (the target) with a more familiar one (the source). For example, one model of the structure of an atom (target) is the arrangement of planets orbiting the sun (source) (Tregidgo & Ratcliffe, 2000).

The source and target are two different entities, with the source being something more familiar than the target, although they share a certain degree of similarity. The relation between a target and a source (which also can be called an analogue) is referred as an analogy or more precisely, an analogical relation. This relationship implies that a model is a form of representation of a target, which is constructed on the basis of the analogical relation between the target and a source. It is the analogical relations that make a model a model. Mental models are unstable and the students' ability to operate or use their mental models in order to explain the events that involve the use of a visual model is very limited, so the need for ongoing training to build it (Coll, 2008; Devetak, 2009; Davidowitz, 2010; McBroom, 2011).

2.13.2 Typologies of models

According to Harrison & Treagust (2000b), there are a number of benefits in having a typology of models. For example, a typology of models can help alert teachers and researchers to the conceptual demands arising from different types of models. With a typology of models, teachers should be able to select the proper model type for their lessons consistent with their students' level of cognitive ability. It also helps teachers to understand the entities of which the models are constructed and of the nature of the case-effect relationship operating within them. In general, models can be divided into two categories namely *mental models* and *expressed models* (Coll, France, & Taylor, 2005). In broad terms, mental models are cognitive structures that are based on new understandings, prior knowledge, existing ideas and past experiences that we use to interpret and explain events in our world (Moseley, Desjean-Perrotta & Utley, 2010). In other words, mental models are models that implicitly exist in our mind. Mental models are conceptual frameworks consisting of generalisation and assumptions from which we understand the world and take action in it. We may not even know that these mental models exist or are affecting us. When mental models are expressed in the public domain via action, speech, writing, text or using other types of symbols, they are called *expressed models* (Gilbert, 2000). When expressed models that gain acceptance among a community of practice, say among scientists, they become *consensus models*. Simplified versions of consensus models which are used in education are called *curricular models*. The consensus models that are currently used in the field of science are called *scientific models*, and those scientific models that are later superseded are referred to as *historical models*. Models, that constitute elements or attributes of different historical models and that are treated as if they constituted a coherent whole, are called *hybrid models.* Expressed models can be categorised based on the modes of representation (Gilbert, 2000). Modes of representation describe the medium of a model that represent the attributes of its target. For instance, chemical structure of water molecule can be represented either with a concrete model of polystyrene balls showing how hydrogen and oxygen atoms are arranged in the molecule, or a Lewis structure showing the sharing of valence electrons between hydrogen and oxygen atoms. Expressed models often require multiple modes to convey the information of the target. Boulter & Buckley (2000) introduced an additional dimension, other than modes of representation, to the categorisation of expressed models, that is the attributes or characteristics of representation which include the type of quantification (quantitative or qualitative), behaviour through time (static or dynamic), and reproducibility of the behaviour (deterministic or stochastic). Based on this dimension, Boulter & Buckley (2000) derived a typology of models. This typology shows the relationship between the modes of representation with a model and how it is represented.

2.13.3 Models in Science

According to Gilbert (2000), Progress in science is often related to the production of a series of models, which are used for the simplification of phenomena, and ultimately to explain phenomena. Matthews (2007) observed that there are a vast number of models in various disciplines in science. Here are some examples:

The 'billiard ball,' 'plum-pudding' and 'solar system' models of the atom, the 'lattice' model of salt structure, the fluid-flow model of electricity, the double helix model of the chromosome, the 'survival of the fittest' model for population expansion in ecosystems, the particle model of light, the 'big bang' model in cosmology, the '3-body' model for sunearth-moon interaction, full dinosaur models from bone fragments in palaeontology, the plate-tectonic model in geophysics, the scores of mathematical models in hereditary and population studies, the thousands of mathematical models in economics, engineering, and so on (Matthews, 2007). The great value of using models in science as representations is that they enable the complex nature of a target system, which is normally abstract, to be made more apparent or obvious by providing specific information about the nature of the target system such as its structure, behaviour, and mechanism (Buckley & Boulter, 2000). In other words, the main function of models as representations is simplification or approximation of the target system Boohan (2002); Coll (2006); Gobert & Buckley (2000), which is done by selecting or excluding certain features of the target system to create a simpler and manageable piece of information (Mäki, 2001; Oh & Oh, 2011; Van Driel & Verloop, 2002). Therefore, a given model in science is an inherently incomplete or partial version of a target, which only displays and/or performs specific attributes of the target, and thus can also be considered as an idealisation or abstraction of the target system (Portides, 2008). Although models may not be able to fully represent a target system, any loss of accuracy is compensated for by gains in clarity (Coll, 2006). Models in science perform at least two representational functions, that are representation of the reality and of scientific theory (Chamizo, 2013; Espinet, Izquierdo, Bonil, & De Robles, 2012; Frigg & Hartmann, 2006; Mäki, 2001). In terms of representation of the reality, models can be regarded as alternate objects that consist of a conceptual representation of a real thing. Good examples of models that represent a phenomenon are, a human skeleton model representing the human bones structure; scale models of an aeroplane, which can be used for studying the real design of aeroplane aerodynamics; and scale models of the Solar System. Scientists use such "models to represent aspects of the world" (Giere, 2004). There are diverse aspects of the reality that are represented by a model which include observable or unobservable objects, properties, states, processes, and sequences of events (Oh & Oh, 2011). Hart (2008) says that: the representations, concepts, relationships and explanatory entities that figure in the model are not given in the phenomenon itself. They are overlays on reality, produced through the human activities of striving to understand, predict and control the physical world (Hart, 2008). A good example of model that is used to understand and predict the physical world is the weather forecast model, which is constructed based on collections of quantitative data of the atmospheric state and may include temperature, barometer pressure, humidity, and wind velocity, and the correlation of these data with the weather conditions. With this weather forecast model, we are able to predict the weather of a given location and time. Therefore, models can provide representations for the reality, and are used to interpret and comprehend complex natural phenomena. Models in science are, however, not only representational of the real world but can also be created to express theoretical ideas. In other words, models function to represent a scientific theory by interpreting the laws, axioms or principles of that theory (Espinet, 2012; Frigg & Hartmann, 2006). Similar to representing the real world, this function involves various idealisations, approximation, and assumptions of the theory of interest. The function of models in representing a theoretical idea can be exemplified by the chemical bonding models of the hydrogen molecule, which can be based on either the valence bond theory or molecular orbital theory. The distinct representational functions of models as links between the real world and scientific theory are not mutually exclusive because "scientific models can at once represent in both senses" (Frigg & Hartmann, 2006). Science itself is a way of understanding the real world, usually through the formation of theories. Thus, constructions of models based on scientific theories are indirectly a way of modelling the real world. Scientists use models to help them comprehend and communicate about a phenomenon, including inferring, and predicting behaviour about the phenomenon (Chamizo, 2007, 2013; Espinet, 2012; Oh & Oh, 2011).

2.13.4 Modelling

Modelling can be thought as the process of forming and constructing models, and this always involves mental models. However, the term modelling can be more than just the act of producing a model. Modelling is a dynamic and continuous process of creating, testing and communicating idea (Justi & Gilbert, 2002c; Maia & Justi, 2009). A basic view of modelling proposed by Suckling et al (1978), see it as a linear process that involves: recognition of the existence of a problem and making a decision to tackle using a model, delineation of the system to be studied, formulation of questions, construction of the model, running the model, and analysing results and implications. In contrast, Justi & Gilbert (2002a) developed a model of modelling as a non-linear process and emphasis is placed on mental models as central to the formation of models. Modelling, according to Justi & Gilbert (2002a), involves several stages: determination of purpose, selection of source, construction of mental model, expression of models, testing and refining the mental model, and determination of the limitation or scope of the model. Additionally, the model of modelling process suggests that the process of modelling is a cycle, in which models are continuously refined and perhaps used to produce more models for a particular system. In a similar manner, working from Robert Karplus' Learning Cycle, Halloun (2006) proposed the 'modelling learning cycle.' This cycle consists of five phases: exploration, model adduction, model formulation, model deployment, and paradigmatic synthesis. Drawing from these models of modelling, there are few common characteristics that can be identified. All of these models of modelling involve cyclical processes, including the process of identifying the real world phenomena, developing the model, testing, and remodelling.

2.14 Mental models

Mental models are psychological representations of real or imaginary situations. They occur in a person's mind as that person perceives and conceptualises the situations happening in the world (Franco & Colinvaux, 2000). Mental models are related to what people have in their heads and what guides them using these things in their minds. Mental models are generative (Franco & Colinvaux, 2000). This means that people or students' can produce new information and make predictions while they are using mental models. In cognitive psychology, the mental model construct is something that needs theorisation or an explanatory theory of cognitive phenomena. The cognitive psychology focuses on the nature of mental models itself, hypothesising on its construction and the way humans perform cognitive tasks such as reasoning, inference, and language comprehension (Johnson-Laird , 2004a, 2004b). Despite the wide applications of the notion of mental models which have produced a wide variety of definitions, mental models as a term can be distilled out as a form of hypothetical internal representation of external objects or a body of knowledge Rapp (2005), which is used to accomplish cognitive functions or tasks such as understanding, reasoning, prediction, and problem solving (Burns, 2001; Gentner, 2001; Greca & Moreira, 2002).

2.14.1 Nature of mental models

Mental models as ‘the structural analogues of the world’ are among other postulated forms of mental representations such as “propositional representations which are strings of symbols that correspond to natural language” and “images which are the perceptual correlates of models from a particular point of view”. Mental models are also distinguished from schemas (Brewer, 2003). In that: Schemas are integrated "packets" of information that can be used to construct mental models of particular objects or situations. A mental model can be viewed as an internal representation of aspects of a world, including a representation of the individual. A mental model will often include actual or imagined event sequences. Therefore, mental model can be viewed as an integrated representation of numerous hierarchically schemas, organised in whole or in part, which will be used to make decisions and guide an individual’s behaviour. A major function of the internal model is to allow *"mental simulations"* of the outcomes of alternative possible scenarios. Although mental models have been studied as a form of hypothetical construct from different perspectives, a general view about the nature of mental models that can be drawn is that they serve as a mental simulation for a system (Johnson-Laird, 2005a, 2010; Nersessian, 2008). In this sense, an individual is able to ‘run’ a mental model internally in his/her mind’s eye and observe the behaviour of the system without having the actual system present

(Gentner, 2001). In other words, a mental model is a set of icons or tokens, which represent entities comprised in the system. For example, an atom mental model may comprise of icons such as a sphere that represent the nucleus of the atom, smaller spheres that represent electrons, and round lines that represent orbits. Although a mental model is considered as analogical to its external system, one important characteristic of a mental model is that it is commonly incomplete and approximate, a simpler version of the system it represents, and rather 'unscientific'. Mental models enable individuals to make inferences and predictions, to understand phenomena to decide what action to take and to control its execution. Similarly, the literature also provides evidence that mental models are necessary in human logical reasoning. This basic tenet about the roles of mental models in human reasoning (also called model-based reasoning) is incompatible with the notion in the role of formalism (e.g. rules of logic, the Euler circle, Venn diagram, etc.) in the process of reasoning (Johnson-Laird, 2004a, 2010).

2.14.2 Typologies of mental models

Although mental models are implicit in nature and more challenging to classify, there are a number of typologies for mental models. As with expressed models, mental models can also be categorised based on the entities that are represented by the mental models. For example, mental models that represent physical objects or phenomena such as chairs, cars, animals, and computers, can be called *physical mental models*. *Conceptual mental models* are mental models used to "represent abstractness, logical operators such as conjunction or disjunction, truth or fiction stories," good or bad behaviour, and physical or chemical change. Another way of classifying mental models is based on the quality of representation of the target system. Vosniadou & Brewer (1992) classified children's mental models of the earth into *scientific mental* *models*, *initial mental models*, and *synthetic mental models*. Scientific mental models can be considered as mental models that are consistent with scientific models, whereas initial mental models are mental models that children possess prior to formal learning about a phenomenon. When children are exposed to scientific information about a particular phenomenon, they try assimilating the information into their naive theoretical framework. The end results of this assimilation form what are called synthetic mental models. In other words, a synthetic model is a mixture or integration of children's initial mental models and scientific models, which is still embedded in their naive theory

2.14.3 Students' mental models of scientific ideas

Mental models can be regarded as the products of learning (Henderson & Tallman, 2006). It is reported that mental models also play important role in the process of learning because learning generally can be viewed as mental modelling. Thus, mental models are considered important in learning science since it is assumed that they provide valuable information about students' science conceptual frameworks or underlying knowledge structures (Coll, 2005). Therefore, capturing students' mental models is one way to understand the content and structure of students' knowledge of scientific concepts, as well as reflecting students' beliefs and interpretation of a system. There is now a large body of research on students' understanding about scientific ideas for various domains. Some examples include mental models about chemical phenomena (Chittleborough, 2004), chemical bonding (Coll, 2008; Coll & Treagust, 2001, 2002, 2003a, 2003b; Taber, 2003), matter (Adbo & Taber, 2009), chemical substances (Dalton, 2003), atoms and molecules (Harrison & Treagust, 2000a), acids and bases (Lin & Chiu, 2007, 2010), atomic structure (Park & Light, 2009), chemical equilibrium (Chiu, Chou, & Liu, 2002), organic chemistry (Treagust, Chittleborough, & Mamiala, 2004), heat conduction (Chiou & Anderson, 2010), electricity (Borges, Clement & Steinberg, 2002; Jabot & Henry, 2007), light (Hubber, 2006), earth and cosmology (Nobes et al., 2003; Panagiotaki, Nobes, & Potton, 2009; Straatemeier, van der Maas, & Jansen, 2008; Vosniadou, Skopeliti, & Ikospentaki, 2005), and the environment (Shepardson, Wee, Priddy, & Harbor, 2007). Analysis of this body of research reveals common findings about students' mental models for scientific concepts. Most researchers reported that student' mental models are not consistent with the actual scientific or teaching models, and can be considered flawed, often with misconceptions (Coll & Treagust, 2003a, 2003b; Taber, 2003). Some research about students' mental models and conceptions suggest that there are a number of factors that are capable of influencing the construction of their mental models.

2.15 Models and Modelling in science Education

Ideas pertaining to models and mental models can be discussed around origins, definition, and typologies. Another aspect of interest and relevant to this study in discussing models, is their application in science teaching and learning. Using models in science education has long been recognised as essential by education researchers. As indicated above, models play a key role in science in the representation of systems (Mäki, 2001; Oh & Oh, 2011; Silva, 2007; Van Driel & Verloop, 2002), are useful in assisting in describing and understanding their structure or properties.

2.15.1 Models and students' learning of science

Teaching science using models, such as teaching models or curricular models, which are usually analogical models, enables teachers to present and explain phenomena that are difficult to be shown to students' directly (Boohan, 2002; Coll, 2005). This provides simplified pieces of information about the structure, behaviour and mechanism of the system (Boulter & Buckley, 2000). Such systems might include: phenomena that are too small to be seen using the naked eye such as microorganisms, living cells, and atomic structure; things that are too big to see as a whole such as solar system and volcanoes; processes that occur too fast for detection using human senses, such as collision and flying; processes that take a long time to complete such as metamorphosis and foetus growth; and finally complex systems such as the weather system, nuclear reactors and the internal combustion in the diesel engine. In the pedagogy of science, models are frequently used to represent the ideas or theories of science about scientific phenomena that are often abstract and conceptual. Expressed models, especially those that are concrete and visual such as scale models, maps, and diagrams, can be used to portray scientists' understanding of the phenomena. It is believed that such models promote mental model construction and manipulation of abstract structures and functions of phenomena (Harrison & Treagust, 2000b; Treagust, 2004). With this concrete model of particles, students' are able to perceive that matter is made from discrete particles, and they can come to understand how they are arranged in the different states of matter. Such an approach to teaching science is consistent with a constructivist view of learning, where students' ideas are developed using their familiar or previous knowledge (Boulter & Buckley, 2000; Matthews, 2007). For these reasons, models can be considered as instructional tools, aiding students' understanding of conceptually salient features of phenomena (Coll & Lajium, 2011). Consequently, the application of models as instructional tools in science pedagogy also includes the use of multiple models to represent scientific idea of the same entity or phenomena that may enhance students' understanding of scientific concepts (Coll, 2006; Oh & Oh, 2011).

2.15.2 Models in teaching science

The literature suggests students' confusion in using models when learning science could result from the way science is taught (Taber, 2008). One observation concerning teaching practices is that teachers tend to emphasise the content of the teaching or scientific models, instead of modelling (Coll & Lajium, 2011; Van Driel & Verloop, 2002). In this pedagogy, teachers do not communicate much about the nature of models used in science teaching and their role in constructing knowledge about the system that the models are intended to represent. This lack of communication suggests that teachers are not aware of or do not pay much attention to their students' ideas about models and modelling (Justi & Gilbert, 2003a). It seems that students' are being immersed into the realm of models, instead of the reality, without knowing the origin or theoretical background of models (Justi, 2000; Matthews, 2007). The way teachers use models in school science could be related to the teachers' view of models as instructional or communicative tools, with the purpose of making the abstract more concrete which is considered pivotal in facilitating understanding of science content (Justi & Gilbert, 2003a). Rarely do teachers recognise that models are used in aspects of scientific inquiry like experimentation, formulation of hypothesis or predictions, improving or even building new theories, and generating new questions (Oh & Oh, 2011). Teachers tend to see models as instructional tools of science content rather than being an aspect of the nature of science (Schwarz et al, 2009). Additionally, similar to students, teachers are also reported to be confused between physical models and the reality (Justi & Van Driel, 2005). This confusion is demonstrated by their transferring of unshared attributes of models to the target system. These findings signify that teachers' understanding of the nature of models and modelling in science are limited (Crawford

& Cullin, 2004). Therefore, in order for models and modelling to serve the purpose of science education, they need to be taught effectively, and the improvement of model based teaching is critical (Coll & Lajium, 2011).

2.16 Models of chemical reactions

Chemistry is the science of matter. An important part of chemistry is the understanding of the changes of matter, both in physical changes and chemical changes. The following sections describe some models that attempt to explain the chemical reactions.

2.16.1 Transmutation Model

The foundations of understanding chemical reactions or transformation of matter probably dates from the Greek philosophers, about 300 BC. At this stage, chemical reactions, or rather the formations of new substances were viewed as the change of elements, which varied slightly among the Greek philosophers such as fire, water, air and earth into new substances – a *transmutation model*. The theoretical ground for the transmutation model of material transformation is mainly philosophical or mythical (Ede, 2006). For example, Thales said that the cosmos and matter originated from water, and his student, Anaximader expanded Thales' idea explaining that materials are made from '*apeiron*' – an entity that makes up the whole world. The Greek philosophers' transmutation model of chemical reactions can be presented as the chemical equation below.

$$\text{Fire} + \text{Water} \longrightarrow \text{Air}$$

The idea of materials being made from minute particles can also be traced back to Greek philosophy. Anaxagoras believed that materials were formed from minute particles of elements, which he called *'seeds,'* whereby these seeds combine with other similar seeds to form materials. These ideas of material transformation may have been the basis of Aristotle's matter theory which influenced the understanding of chemical reactions in Middle East and Europe until the seventeenth century (Ede, 2006).

2.16.2 Particle Model

Similar to Anaxagoras' 'seeds' idea, Democritus viewed matter as being formed of indivisible particles – the atomic notion of matter. The essence of his theory was that the unchangeable solid atoms of elements, earth, air, water and fire could be entangled together to form visible substances. Democritus's atomistic matter, although rejected by Aristotle, influenced the Western Europe philosophers in the 1600s especially Boyle and Newton. This atomistic view of matter is consistent with the idea of the *particle model* of chemical reactions. The basic idea of the particle model is that a chemical reaction is a process of interactions between particles (or corpuscles) as a result of a force, and that they combine in a specific form, which Boyle refers to as *'minima naturalia,'* equivalent to the modern concept of molecule (Ede, 2006). At this stage, chemical reactions were explained on the basis of forces interacting between particles.

In the 1700s, the particle model of chemical reactions was further advanced through Lavoisier's work. Among other important features of chemical reactions based on Lavoisier's ideas, the idea was that mass is conserved, and that there are more than four elements that contribute to chemical reactions. However, up to this point, the particle model of chemical reactions had not departed much from the transmutation models of chemical reactions.

When Dalton, in 1808, proposed that the particles or elemental atoms remain the same even if they combine with other type of atoms, did we see the basis of the modern understanding of atomic theory (Ede, 2006). In this sense, chemical reactions involve interactions between specific particles, and due to these interactions, rearrangement of atoms occurs to form new substances. Therefore, in chemical reactions, only the atomic composition of substances changes when new substances are formed, but the atoms remain the same, which means the mass is conserved (*law of conservation of mass*).

2.16.3 Collision Model

A refined model of the particle model of chemical reactions based on chemical kinetics is the collision model. In this model, the collision of molecules is the first step in chemical reactions Upadhyay (2006), and the basic assumption is that the reactants molecules are represented as hard spheres with definite radii (Wright, 2004). In order for a chemical reaction to occur, the molecules or particles of reactants, need to undergo a process of collision – the more frequent the collisions, the higher the probability for a chemical reaction to occur. Therefore, the collision model of chemical reactions explains the rate of reaction or the 'speed' of reaction. The frequency of collisions is considered as a function of the chemical reactions; the greater the collision frequency, the more often reactions occur, and the greater rate of reaction. However, not all collisions lead to chemical reactions, and a collision that leads to chemical reactions is referred as an *effective collision*. An effective collision is when a new species of molecules are produced after the collision.

2.16.4 Thermodynamic Model

Chemical reactions in thermodynamics are portrayed mainly in terms of the change of energy that is studying the relation of chemical changes to energy changes. An important thermodynamic aspect of chemical reactions is work, how a chemical reaction is able to achieve some kind of motion against an opposing force. For example, a chemical reaction happening in a battery does work when it pushes electric current in a circuit and internal combustion in a vehicle does work when pushing pistons (Atkins & Jones, 2010). To do work, energy is required. Therefore, energy can be described as the capacity of a system to do work. The more energy a system has the more work it is potentially able to do. For example, a "hot compressed gas can do work more than the same gas after it has expanded and cooled" (Atkins & Jones, 2010), or a mixture of kerosene and air has more potential to do work than the mixture of products formed after combustion. Although energy can be transformed from one form to another, the energy of the universe is conserved – this is the First Law of Thermodynamics (Zumdahl & Zumdahl, 2010). Although the *universe* that we live in now is a complex entity, it consists of the *system*, where the part of the universe that we set for its boundaries separates it from the rest of the universe, the surroundings (Jenkins, 2008; Zumdahl, Zumdahl, & DeCoste, 2007). Therefore, a chemical reaction can be considered as a system in the universe involving reaction and chemical change. The burning of a candle is an example of a chemical reaction system, while the surroundings include the air in the room and anything else other than the reactants (i.e. candle and oxygen) and products (i.e. carbon dioxide and water).

2.17 Summary

The literature above suggests that models and modelling play a significant role in science and science education. Science involves the creation of models, and scientists construct models to represent scientific phenomena, and use them as tools to discover new knowledge. Learning science can be considered as a process of understanding what scientists understand about scientific phenomena as portrayed or represented in various types of models such as analogical models, physical models, and theoretical-symbolic models. In other words, learning science can be seen as a process of modelling, which involves producing models and mental models either directly from the phenomena, or from what has been modelled by the scientist. Mental models are considered crucial in the learning of science, apart from the process of modelling; they are also a good indicator of students' understanding of science concepts since they provide insights into students' representation of scientific concepts. Mental models, as either representation tools or reasoning tools, are used directly or indirectly by science educators in examining students' ideas or conceptions about science concepts such as atomic structure, chemical bonding, and chemical reactions. It is widely reported in the literature that students' mental models are either not consistent with the scientific or teaching models, contain some misconceptions, or consist of a form of synthetic-hybrid models. Apart from learning about the nature of chemical materials, chemistry education also emphasises students' acquisition of knowledge about interactions of matter and energy. This knowledge is not only important for their academic goals, but also helps them to understand the world around them, through understanding the most fundamental ideas of chemistry, *inter alia*, particulate nature of matter, particle collisions, and dispersal of mass and energy. Therefore, it is considered important for chemistry educators to understand students' mental models of chemical reactions and balancing of chemical equations in order to assist students' acquiring knowledge of much chemistry. Although there are some studies on students' understanding of chemical reactions, most are limited to addressing specific chemical reaction concepts in isolation, such as conservation of mass or matter, redox reactions, acid and base reactions, spontaneity of reactions, and chemical kinetics. Little attention has been given to understanding students' mental models, around the whole notion of chemical reactions. It is therefore, of interest to study students' mental models of chemical reactions in a holistic sense due to the interrelated nature of chemistry concepts.

CHAPTER THREE

METHODOLOGY

3.1 Overview

This chapter deals with the research methodology employed in the study. It begins with an overview of research design. This overview is followed by a discussion of the research methods and approaches for data collection. The discussion continues with a description about the nature of qualitative interviews, and a detailed explanation of the development of the interview protocol for the inquiry along with the procedure used for the interviews. It further explained how the population and sample were selected and then gave reasons for the choice of a particular sampling technique. Other areas covered include instruments used for data collection, validity and reliability of the research instruments. The chapter concludes with how the data collected were analysed to determine the effectiveness of the intervention used.

3.2 Research Design

Research design establishes how a research project is conducted (Denscombe, 2010). It describes components of the study including the theoretical perspective of research, details of the procedures by which the study is conducted including sampling, methods of data collection, analysis of data, and other aspects of the research plan (Blaikie, 2000). A research design is the logic that links the data to be collected and the conclusions to be drawn to the initial questions of a study; it ensures coherence (Gomm, Hammersley & Foster, 2000).

A research design explains how key components of research such as the philosophical assumptions, research methods and plans, purpose and research questions link and are consistent with each other (Denscombe, 2010). The research design also provides justification for the choice of strategy employed in the inquiry in relation to the research questions (Denscombe, 2010). Denscombe (2010) also stated that research methods provide suitable information that answer the research questions and demonstrating the sense of 'fit for purpose' of the research design. Research design is a plan or blue-print that specifies how data relating to a given problem should be collected and analysed (Amedahe, 2002). He further explained that for every research study, the choice of a particular research design must be appropriate to the subject under investigation, and that the various designs in research have specific advantages and disadvantages. Some examples of research designs according to Amedahe (2002) are survey, case study, quasi-experimental and action research or experimental.

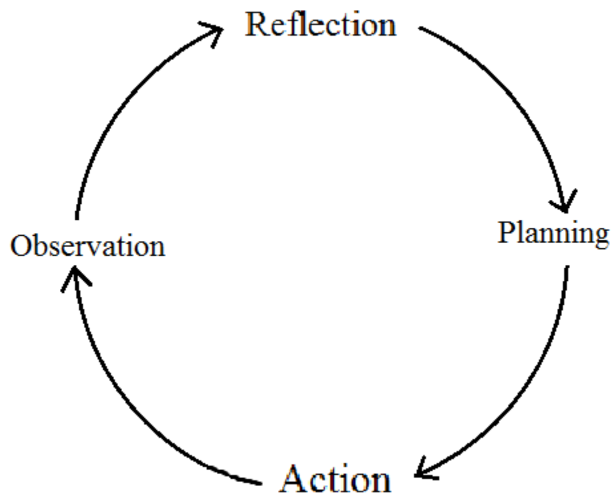
Case Study

This involves collecting data, generally from only one or a small number of cases. It usually provides rich detail about those cases of a predominantly qualitative nature. Case studies focus on one (or just a few) instances of a particular phenomenon with a view to providing an in-depth account of events, relationships, experiences or processes occurring in that particular instance (Denscombe, 2010). According to Yin (2003), a case study design should be considered if: the focus of the study is to answer "how" and "why" questions; you cannot manipulate the behaviour of those involved in the study; if you want to cover contextual conditions because you believe they are relevant to the phenomenon under study; or the boundaries are not clear between the phenomenon and context. Case study method enables a researcher to closely examine the data within a specific context. In most cases, a case study method selects a small geographical area or a very limited number of individuals as the subjects of study. The greatest strength of case study is that it allows the researcher to concentrate on a specific instance or situation and to identify, the various interactive processes at work

(Cepni, 2010). These processes may remain hidden in a large scale survey but may be crucial to the success or failure of the study.

Action Research

Action research is a process in which participants examine their own educational practice systematically and carefully, using the techniques of research (Ferrance, 2000). Action research involves systematic observations and data collection which can be used by practitioner-researcher in reflection, decision making and development of more effective classroom strategies (Parson & Brown, 2002). Although there are many types of research that may be undertaken, action research specifically refers to a disciplined inquiry done by a teacher with the intent that the research will inform and change his or her practices in the future. This research is carried out within the context of the teacher's environment—that is, with the students and at the school in which the teacher works—on questions that deal with educational matters at hand. The linking terms, action and research, highlight the essential features of this method: trying out ideas in practice as a means of increasing knowledge about or improving curriculum, teaching and learning process (Seidu, 2007). Mills (2000) is of the view that the purpose for choosing action research is to effect positive educational change. By this, Mills (2000) implies that an action research is resorted to in order to solve an immediate problem in a given situation to bring about a positive change. Labaree (2011) asserts that the essentials of action research design follow a characteristic cycle where initially an exploratory stance is adopted. This in his view helps the researcher to learn and understand the problem under consideration so that some form of intervention strategy could be developed. The intervention according to Labaree (2011) is carried out during which pertinent observations are made in various forms to collate and examine data to improve the intervention strategy. The approach enables researchers and their participants to learn from each other through a cycle of planning, action, observation and reflection (Steepless, 2004). According to Steepless (2004), the cyclical nature fosters deeper understanding of a given situation starting with conceptualising and moving through several interventions and evaluation. Figure 1 shows the cyclical nature of the action research model described by Steepless (2004).



Action Research Model

They include reflecting on one's practice and identifying a problem or concern, planning a strategy or intervention that may solve the problem, acting or carrying out the plan, and finally, observing the result or collecting the data. This cycle is continually repeated seeking improvement until the problem is solved (Steepless, 2004). Ferrance (2000) proposed that action research refers to a disciplined inquiry done by a teacher with the intention that the research will inform and change his/ her practices in future. To Ferrance (2000), it is an interactive process rather than a one-off exercise of transmitting information by the teacher and that it is mostly chosen when circumstances require flexibility, the involvement of the participants in the research, or change must take place quickly or holistically.

In this study, action research design approach was adopted and this design sought to find an immediate solution to students' inability to answer questions in chemical reactions and balancing of chemical equations correctly. An action research method allowed for minimum disruption of the normal routine of the school and was more manageable since the Researcher did the study during the assigned chemistry and integrated science periods.

Research done with the teacher-student in a setting with which the teacher is familiar helps to confer relevance and validity to a disciplined study. This will intend help teachers to pick up threads suggested in academic circles, and weave them in to their own classroom.

Research and reflection allow teachers to grow and gain confidence in their work. Action research projects influence thinking skills, sense of efficacy, willingness to share and communicate, and attitudes toward the process of change. Through action research, teachers learn about themselves, their students, their colleagues, and can determine ways to continually improve (Ferrance, 2000).

Isolation is one of the downsides of teaching. Teachers are often the sole adult in a room of children, and have little or no time scheduled for professional conversations with others. Action research in pairs or by teams of teachers allows time to talk with others about teaching and teaching strategies. By working on these teams, teachers must describe their own teaching styles and strategies and share their thoughts with others. As a team, they examine various instructional strategies, learning activities, and curricular materials used in the classroom. Through these discussions with colleagues they develop stronger relationships (Ferrance, 2000).

Finally, action research is resorted to in order to solve an immediate problem in a given situation to bring about a positive change. Opportunities for teachers to evaluate themselves in schools are often few, and usually happen only in an informal manner. Action research can serve as a chance to really take a look at one's own teaching in a structured manner. While the focus of action research is usually the students, educators can also investigate what effect their teaching is having on their students, how they could work better with other teachers, or ways of changing the whole school for the better.

Quantitative and Qualitative Methods

Research methods have traditionally been described as quantitative or qualitative. However, Scott and Usher (2011) maintained that the distinction between quantitative and qualitative methods should not be based solely on the research instruments but also on the way they are used because some of the so called quantitative instruments can be used to collect data which is analysed qualitatively. In these instances, these instruments are simply devices for gathering information.

In terms of data collection, quantitative methods "require the use of standardised measures so that the varying perspectives and experiences of people can be fit into a limited number of predetermined response categories to which numbers are assigned" (Patton, 2002) – predominantly involving quantity and quantifying (Grix, 2004). Researchers develop concepts and measurement procedures such as structured observations, standardised tests, self-report questionnaires and attitude inventories to produce numerical information as an empirical representation of the phenomena. These measurement tools usually contain specific questions and responses developed in advance of a study (Creswell, 2012). Quantitative methods are, therefore, by nature highly structured.

Qualitative methods, on the other hand, concern meaning that is given by individuals to their experiences in the world and data are generated through interpretation of the quality and texture of experience rather than assigning numerical values (Grix, 2004; Willig, 2008). Data collected from qualitative methods are drawn from the "perspective of the people who are being studied". The methods typically employed include interviews, documentary analysis, and participant observation as means of recording as much information as possible for the study, in the form of texts, images or other non-numerical information, but may include some numerical data. Instead of using specific questions, qualitative methods use more general questions. These general questions are often rather dynamic, changing and emerging during data collection (Creswell, 2012). The form of data collected in quantitative and qualitative research determines the process for data analysis.

Ultimately, quantitative methods enable researchers to test hypotheses and theories (Grix, 2004). Conversely, in qualitative data, text and image databases are analysed to describe the phenomenon of interest such as people, places or a community (Creswell, 2012). Instead of numerical measures, the qualitative database is described or represented in the form of themes or categories that carry interpreted meanings of the data and 'thick description' of the phenomenon (Grix, 2004).

3.3 Research Instrument

Research instruments are tools used to collect data to answer the research questions. There are various procedures of data collection (Zohrabi, 2013). According to him, some of them are questionnaire, interview, classroom observation and test. These instruments are discussed below.

Questionnaire

Questionnaire is the most frequently used instrument or tool in educational research for obtaining the data beyond the physical reach of the researcher which for example may be sent or mailed to people who are thousands of miles away. According to Jack and Norman (2003), a questionnaire is a written document that has a set of questions given to respondents or used by an interviewer to ask questions and record answers. The authors pointed out that there are two forms of questionnaire: closed-ended and open-ended form.

The closed-ended form is also known as restricted or structured calls for short, check-mark and require the respondent to provide "yes" / "no" responses or rank alternatives provided based on how one feels about the issue. The respondent's choices are limited to the set of opinions. However, the open-ended questionnaire which is also termed as unrestricted or unstructured calls for a free response in the respondent's own words. The respondent frames and supplies the answers to the questions raised in the questionnaire. Questionnaires are used when researchers want to obtain information on a large number of issues. They are usually employed in survey researches.

Interview

An interview involves posing questions to respondents for answers in a face-to-face situation or by phone (Amedahe, 2002). According to him, there are many types of interviews, each of which differs from the others in structure, purpose, role of the interviewer, number of respondents involved in each interview, and form and frequency of administration. These types however fall under two main categories: *structured and unstructured*.

The structured interviews follow specific questions to be asked and the orders of the questions are pre-determined and set by the researcher .They are based on a strict procedure and a highly structured interview guide. However, the unstructured interviews have no strict procedure to follow. There are no restrictions in the wording of the question or the order of the question. Interviewers develop questions as they go along and probe respondents' answer with follow-up inquires.

Merriam (2001) discloses that, interview is the best technique to use when conducting intensive case studies of a few selected individuals. Interview is useful when the informant cannot be directly observed. Generally, an interview can be viewed as a way of getting information or perspectives from a person through engagement in an 'interactional exchange of dialogue.' Interviews can be conducted through one-to-one interaction, with individuals or focus groups, and in face-to-face situations or via the telephone or the Internet (Mason, 2002). Questions in interviews differ from surveys and questionnaires because they are posed by interviewer(s) and the responses are given by the interviewee(s) verbally. Structured or closed quantitative interviews can be viewed as an alternative to self-report questionnaires (Mason, 2002). Since the questions and choice of responses are pre-formulated and rigidly sequenced – they are a form of verbal questionnaire. The locus of control in the interview is mainly the questions, where the questions themselves function as the instruments, while the interviewer verbalises the questions and choices of responses. As in self-report questionnaires, a structured interview facilitates numerous questions, is less time consuming, and enables straight-forward data analysis (Patton, 2002).

Despite these advantages, this technique of interview serves a similar function to questionnaires and poses the same limitations; that is, inadequate at providing in-depth understanding of participants' view. Moreover, the limited choice of responses requires interviewees to select their experiences and feelings to fit the questions, which can lead to distortion of meaning. Thus, a structured interview is deemed unsuitable for the present study, which requires more than such just superficial information.

Observation

This involves watching people, events, situations, or phenomena and obtaining first-hand information relating to particular aspects of such people, events, situation or phenomena (Annum, 2015). It deals with perceiving data through the senses: sight, hearing, taste, touch and smell. According to Annum (2015), there are several type observations. Some of them are participant and non-participant observation.

According to him, in participant observation, the observers actually become members of the group they are supposed to be studying. They observe from inside the group and, ideally, their identity as a researcher is not known. However, in the non-participant observation, observers study their subjects from outside without becoming a part of the environment of the observed.

Observation is one of the important methods for obtaining comprehensive data in qualitative research especially when a composite of both oral and visual data become vital to the research (Annum, 2015). Ary and Razaviet (2002) pointed out that observation is employed when children are to be studied while busy in different activities such as games, dramatics or social services.

3.4 Population

Population is a group of individuals or objects who have the same characteristics (Creswell, 2008, 2012). He further explained that a population defines the limits within which research findings are applicable and that a population could be large or small and a researcher needs to decide what group to use for the study.

3.4.1 Types of population

Target Population

The target population refers to the entire group of individuals to which researchers are interested in generalising their conclusions (Castillo, 2009). The target population contains members of a group that a researcher is interested in studying. The results of the study are generalised to this population, because they all have significant traits in common. The target population usually has varying characteristics and it is also known as the theoretical population. Examples of target population includes all people with AIDS, all school-age children with asthma, all pregnant teens, all SHS 2 students, etc. The above examples showed that, as far as a person falls within this group, the person is part of the population, whether he/she have travelled outside or is sick.

Accessible population

Accessible population is the population which the researchers can readily access, work with, and apply their conclusions (Castillo, 2009). It is also the portion of the population to which the researcher has reasonable access. Accessible population is the subset of the target population. It may be limited to region, state, city, country, or institution. Accessible population is also known as the study population. It is from the accessible population that researchers draw their samples.

Examples of accessible population includes all people with AIDS in Tain district, all school-age children with asthma treated in pediatric asthma clinics in 37 military hospital, Accra in Ghana, all pregnant teens in Seikwa, all SHS 2 students in Tain district, etc. For example, all SHS 2 students in Tain district being the accessible population. In this case, the accessible population is only those who are in SHS 2 in Tain district. If there another SHS 2 student in Berekum municipality, he/she is not part of the population.

In this study, the target population comprised all form two students at Diamono Senior High School in the Jaman North of Brong-Ahafo Region. However, the accessible population was second year Chemistry students in Diamono Senior High School. The choice of SHS form two Chemistry students was made because they had been exposed to prerequisite concepts in the first year and had attained some level of maturity and confidence needed to develop their mental models.

3.5 Sample

A sample is a smaller group which is drawn from a larger population and studied (Robson, 2002; Punch, 2006). A sample is representative of the population to the extent that it exhibits the same distribution of characteristics as the population. The concept of sample arises from the inability of the researchers to test all the individuals in a given population. The sample must be a fair representative of the population from which it was drawn and it must have good size to warrant statistical analysis (Castillo, 2009).

Trochim (2002) points out that there are two main types of sample: probability and non-probability samples. According to the author, probability sample is the type where every member of the population has equal opportunity to be selected into the sample. Probability sampling represents a group of sampling techniques that help researchers to select units from a population that they are interested in studying. Collectively, these units form the sample that the researcher studies. A core characteristic of probability sampling techniques is that units are selected from the population at random using probabilistic methods. This enables researchers to make statistical inferences (i.e., generalisations) from the sample being studied to the population of interest. Every member or element of the population has a probability greater than one of being selected for the sample. Some of the probability samples are simple random, systematic and stratified sample.

Simple random sample is the type where each member of the population under study has equal chance of being selected into the sample. Simple random sample gives the opportunity to have homogeneous representation of the population (Amoani, 2005).

Systematic sample is the type in which the selected subject from the population list is systematic rather than the random fashion (Cohen, Manion & Morrison, 2008). This type is more convenient when dealing with a very large population and a large sample is needed.

Stratified sample is the type where certain subgroups or strata are selected in the same proportion as they exist in the population. Stratified sample involves dividing the population into homogeneous groups, each group containing sample with similar characteristics (Fraenkel & Wallen, 2000). This sample type ensures that different strata in the population are represented. It also increases the precision of the sample and it is convenient for practical purposes.

Non-probability sample is a deliberately selected sample to represent the wider population; it seeks only to present a particular group, a particular named section of a wider population, such as a class of students, a group of students who are taking a particular examination, and a group of teachers. Non-probability sampling represents a group of sampling techniques that help researchers to select units from a population that they are interested in studying. Collectively, these units form the sample that the researcher studies. A core characteristic of non-probability sampling techniques is that samples are selected based on the subjective judgement of the researcher, rather than random selection (i.e., probabilistic methods), which is the cornerstone of probability sampling techniques. Whilst some researchers may view non-probability sampling techniques as inferior to probability sampling techniques, there are strong theoretical and practical reasons for their use. There are several types of non-probability sample: convenience sample, quota sample, snowball sample and purposive sample (Cohen, Manion & Morrison, 2008).

Purposive sample is the type in which the researcher handpicked the people to be included in the sample on the basis of their judgment of their typicality or possession of the particular characteristics being sought (Patton, 2002). Purposive sampling, also known as judgmental, selective or subjective sampling, reflects a group of sampling techniques that rely on the judgement of the researcher when it comes to selecting the units (e.g., people, cases/organisations, events, pieces of data) that are to be studied. These purposive sampling techniques include maximum variation sampling, homogeneous sampling, typical case sampling, extreme (or deviant) case sampling, total population sampling and expert sampling. The different purposive sampling techniques can either be used on their own or in combination with other purposive sampling techniques.

With proportional quota sampling, the aim is to end up with a sample where the strata (groups) being studied (e.g., males vs. females students) are proportional to the population being studied. A convenience sample is simply one where the units that are selected for inclusion in the sample are the easiest to access. For example, 10,000 university students, if we were only interested in achieving a sample size of say 100 students, we may simply stand at one of the main entrances to campus, where it would be easy to invite the many students that pass by to take part in the research. Snowball sampling is particularly appropriate when the population you are interested in is hidden and/or hard-to-reach. These include populations such as drug addicts, homeless people, individuals with AIDS/HIV, prostitutes, and so forth.

In this study, purposive sampling was used to select sample for the study. The Researcher used purposive sample because it gives wide range of sampling techniques that can be used across such qualitative research designs; purposive sampling techniques that range from homogeneous sampling through to critical case sampling, expert sampling, and more. Whilst the various purposive sampling techniques each have different goals, they can provide researchers with the justification to make generalisations from the sample that is being studied, whether such generalisations are theoretical, analytic and/or logical in nature. Qualitative research designs can involve multiple phases, with each phase building on the previous one. In such instances, different types of sampling technique may be required at each phase.

Purposive sampling is useful in these instances because it provides a wide range of non-probability sampling techniques for the researcher to draw on. For example, critical case sampling may be used to investigate whether a phenomenon is worth investigating further, before adopting an expert sampling approach to examine specific issues further. Finally, the Researcher used purposive sample because among the accessible population these students' over depended on teachers for information and their responses to oral questions and classroom exercises revealed some misconceptions.

The sample for the study was second year general science students at Diamono senior high school, Duadaso No. 2, Brong Ahafo Region. The sample size was 30 students and of out these, 24 of them were boys and the remaining 6 were girls.

3.5.1 Sampling Technique

Sampling, according to Amoani (2005), is the procedure whereby elements or people are chosen from a population to represent the characteristics of that population. Kumekpor, (2002) also explained sampling as the use of definite procedure in the selection of a part for the express purpose of obtaining from its description or estimates certain properties and characteristics of the whole. There are two types of sampling techniques that are used in educational research which are probability sampling and non-probability sampling (Cohen, Manion & Morrison, 2008). According to Cohen, Manion and Morrison (2008), in probability sampling, randomness is essential and it is a key element in the process.

On the other hand, non-probability sampling is based on the judgment of the researcher. The authors disclosed that there are several types of sampling techniques and some of them are simple random and stratified (probability), convenience and purposive (non-probability) samplings. According to them, in simple random sampling, all the units of the target population have an equal chance of being selected and that this technique is appropriate when a population of study is similar in characteristics of interest. Stratified sampling involves dividing the population into a number of homogeneous groups or strata. Each group contains subjects with similar characteristics and a sample is then drawn from each group or stratum. Stratified sampling technique is employed when there is a need to represent all the groups of the target population in the sample. Convenience sampling is a form of non-probability sampling which involves choosing the nearest or available individuals to serve as respondents (Amedahe, 2002). This type sampling is employed in qualitative research and in other studies where representativeness is not an issue.

Purposive sampling is also a form of non-probability sampling in which decisions concerning the individuals to be included in the sample are taken by the researcher, based on a variety of criteria which may include specialized knowledge of the research issue, or capacity and willingness to participate in the research (Bernard, 2002). This technique is used when the researcher wants a sample of experts as in the case of a need assessment using the key informant approach.

In this study, purposive sampling was used to select the sample for the study because the Researcher had taught general science classes consistently for the past five years and has observed students' mental models of chemical reactions and balancing chemical equations. Purposive sampling is useful in these instances because it provides a wide range of non-probability sampling techniques for the researcher to draw on. For example, critical case sampling may be used to investigate whether a phenomenon is worth investigating further, before adopting an expert sampling approach to examine specific issues further. Also, the students' responses to questions revealed some misconceptions and some of them also exhibited negative attitudes like laziness, lack of interest and truancy during chemistry lessons.

Students' Learning Progress Monitoring Form

This form was used to collect data on students' progression in the classroom activities during the intervention. The form consists of name of student on the vertical column, exercise number and score on the horizontal column. At the end of each lesson the Researcher marked the exercise and recorded the marks scored against each student. The sum total and average scores were calculated for all the students as well as the individual student for each lesson.

Observational Checklist on student attitude

An observational checklist was used to gather information about students' attitudes to science. The form was used to evaluate students' attendance and participation aspects of attitude in the classroom. It was designed in such a way that it contains some attributes of attitude to be observed and brief remarks or notes. The Researcher wrote observational note after each lesson in order to avoid Hawthorn effect. Hawthorn effect is a form of reactivity whereby subject improve or modify an aspect of their behaviour which is being experimentally measured, in response to the fact that they know that they are being studied (McCarney, Warner, Iliffe, Van Haselen, Griffin & Fisher, 2007).

3.5.2 Validity of the Instrument

Validity means the individual's scores from an instrument make sense, are meaningful, and enable a researcher to draw good conclusions from the sample being studied (Creswell, 2008). He further stated that validity seeks to determine whether the instrument actually measures what it is intended to measure. Cohen, Manion and Morrison (2008) also explained that validation of research instrument must show that it fairly and comprehensively covers the domain or the items that it purported to cover. For a test to be reliable, it also needs to be valid.

Validity is used to assess how well a measure is able to provide information to help improve the study. It can also be used to predict future or current performance. Thus, it correlates test results with another criterion of interest. If the results of a study are not deemed to be valid, then they are meaningless to the study. If it does not measure what we want it to measure, then the results cannot be used to answer the research questions, which is the main aim of the study. These results cannot be used to generalise any findings and become a waste of time and effort. It is important to remember that just because a study is valid in one instance; it does not mean that it is valid for measuring something else.

3.5.3 Reliability of the Instrument

Reliability is the degree to which an assessment tool produces stable and consistent results. There are different types of reliability. These include test-retest reliability, which is a measure of reliability obtained by administering the same test twice over a period of time to a group of individuals. Inter-rater reliability also is a measure of reliability used to assess the degree to which different judges or raters agree in their assessment decisions.

Dependability or reliability in constructivist enquiry should be regarded as a fit between the recorded data and what actually occurred in the natural setting of the inquiry (Cohen, 2007). Dependability is the degree of accuracy and comprehensiveness of the data (Bogdan & Biklen, 2007). Though positivist inquiry requires the application of the same methods throughout the data collection in order to ensure replicability of the result, this requirement is not applicable to constructivist naturalistic inquiries, which tend to include methodological changes and shifts because of a maturation of constructions.

3.5.4 Data Collection Procedure

In this study, data was collected with the aid of the research instruments. The data collection procedure was divided into three phases: pre-intervention, intervention and the post intervention phase.

Pre-intervention phase

This stage of the study lasted for two weeks. The Researcher informed the headmaster about the research work he wanted to carry out in the school in order to solicit his cooperation and assistance. He then liaised with the headmaster to supply all the students with recommended chemistry and integrated science textbooks. A termly scheme of work or forecast was prepared and each student was given a copy to follow. Two past students' were also trained on how to use the observational schedule form at this stage.

Intervention phase

This phase had to do with the implementation of the Multiple Representation Method (MRM). The stage lasted for eight weeks. The students performed activities at this stage and teacher provided feedbacks to students to know their performance from time to time. The Researcher monitored students' activities and intervened when necessary. In this study, five lessons were reported and analysed.

Implementation of the Multiple Representation Method (MRM)

This involved six steps. The steps were explained as follows:

Introduction

The Researcher introduced the lesson by reviewing the students' relevance previous knowledge through question and answer technique. This stage was very essential to arouse the students' attention and help in bridging the gap in learning by activating students' prior knowledge and in taking in the new material.

Practice of the MRM

The Researcher distributed study guides and self-assessment task worksheets to the students. The students' followed the instructional guides, carried out activities independently and also in groups and recorded their findings. The questions regarding students' mental model of simple chemical reactions required the students to use their mental model in transforming chemical phenomena to verbal form and from verbal form to mathematical form (calculations), to interpret the sub-micro visual image of a simple reaction with reactant and the product.

Furthermore, the students' were also asked to describe the product of reaction as well as to perform transformation from verbal statement into a sub-micro (visual) diagram by drawing the reactant and product of a given reaction, and to interpret the reaction occurring in a container. Questions to measure students' mental models with stoichiometry concepts were also given to students' as their self-assessment task.

Students' were presented with samples of solutions and mixtures and asked to generate submicro diagrams of what they had observed, justifying the format of their representation with the accuracy and detail of representations being emphasised.

Finally, the submicro diagrams, which were already an integral part of the teaching methodology of the course, were given more emphasis, and they were subsequently used regularly as an assessment tool to determine whether they could reveal any other misconceptions held by students. However, students who found the task difficult to do might negotiate with the teacher for change or assistance.

Monitoring and intervening

While the students' were working on the given task, the Researcher moved round and observed each individual task. At random, the Researcher asked leading questions which stimulate the students' to think and which were relevant to the assignment or task given. The Researcher intervened in each individual task if he/she asked for a clarification to be made while working on the task. He intervened when the need aroused.

Assessment

The Researcher evaluated the individual student as well as the various working groups using students' checklist and the worksheet task. To evaluate individual understanding, the Researcher made a checklist to keep track of individual points as they work in groups. The expression of students' opinion, asking of questions and contributions during lessons were assessed. For instance, each time an individual asked a significant question, the Researcher awarded one bonus point. Any insignificant question received no bonus point. Each student answered the self-assessment questions on the worksheet. Students' were permitted to help one another during the evaluation exercises.

Scores

Each worksheet exercise taken was marked and scored. The mental model test data analysis is performed by assigning scores to each answer given by the students' (Park, 2006) and Wang (2007) according to the types of student's answer. Scoring technique was performed by assessing the students' answer to a test question with a label indicating their level of achievement. These scores were accumulated for each student.

Individual recognition

The Researcher figured out excellent, good and average students' and rewarded them. Individual scores were announced and students' who have improved over the previous exercise were also rewarded. This was done to recognise individual accomplishment and to encourage the students' to learn hard.

3.6 Data analysis procedure

Data analysis is the process of simplifying data in order to make it comprehensive (Jack & Norman, 2003). According to Bogdan and Bilklen (2003) data analysis refers to the process of systematically searching and arranging the interview transcripts, field notes, and other materials that were accumulated to produce findings. Data analysis is the process of converting raw data collected into usable information.

There were two forms of data gathered in this study; the students' verbal responses and the sketches that they drew in the interviews. All the verbal responses were fully transcribed, which served to familiarise the Researcher with the content and students' generation of ideas about the data (Gibbs, 2007). Each transcript was read carefully several times and emerging patterns were noted. Initial observations and thoughts were also recorded for further analysis. In contrast, the sketches on papers were scanned into digital graphic form. Both transcriptions and digitalised sketches were compiled using SPSS computer software for analysis. The compiled form of interview transcripts were then examined for statements and sketches that could be interpreted as evidence of students' ideas about the target systems that reflected the attributes of their mental models of chemical reactions.

In this study, qualitative data analysis methods were employed. Reports were presented on the lessons and analysed based on the progress of the students from lesson to lesson. The activities carried out, the interactions, the level of participation in the lessons and the progression of the lessons were all grounded in the report. The observations made during the lessons and findings from the five lessons were analysed qualitatively. Discussions of the findings were made based on the research questions. On the basis of analysis the findings, conclusions and recommendations were made.

3.7 Summary

This chapter has provided a description of the methodology and methods of the Study, building on the literature review and theoretical perspective. In order to provide rich information about mental model that co-constructed between participants and the Researcher, qualitative data was considered to be more suitable for this study. This method adapted the semi-structured interviews, approach in focusing various target systems of chemical reactions. Through the semi-structured interviews, students' mental models of chemical reactions and balancing chemical equations were examined.

CHAPTER FOUR

PRESENTATION AND ANALYSIS OF DATA

4.1 Overview

This chapter deals with the findings of the five lessons. Each lesson report was based on the teaching and learning activities that went on in the classroom. A number of Tables and Figures were constructed for easy presentation and analysis of data. The chapter ends with discussion of the findings according to the research questions.

4.2 Report on Lesson 1

Topic: Chemical formulae and chemical equations

Sub-topic: Chemical reaction

Objectives: After studying this, students' should be able to:

1. Define chemical reaction
2. State some examples of chemical reactions

Relevant Previous Knowledge: Students' have seen candle burning. They have also seen people mixing salt and water together and have heard of photosynthesis.

Activity 1: Definition of chemical reaction

Researcher: ***What is a chemical reaction?***

Students' Response:

Natural occurrence: Some of the participants considered a chemical reaction to be a natural occurrence, happening without manipulation. In the thinking of these participants, the changes of substances, which happen in the surroundings such as rusting and ice melting, were part of nature. What they knew was that in our air, there was oxygen, everywhere, even here where we were sitting, except in vacuum. This thing was natural phenomenon in the world. It was like why chickens laid eggs. It is the same with iron rusting.

Change of chemical substances: Students' with this attribute considered a chemical reaction is evident when any change happens to any chemical substance. They also considered that any chemical substances they know of will undergo changes or chemical reactions. Ice melting (which is a physical change) is assumed to be a chemical reaction here purely because it undergoes some changes, which indicates a lack of understanding of the chemical change idea. Substances change from one state to other state through a chemical reaction.

Change in physical properties: Some students presumed that any change is a chemical reaction, and looked for changes in the physical appearance of materials like such as colour, and density, all which they see as characteristics of chemical reactions. However, other students seemed aware that changes of physical properties are related to changes of chemical substances. For chemical reactions, we know it when there is change in colour. We look at its colour change. Like the metal, we know it is silvery and after it is corrode, its colour changed to orange. So, one of the elements in the metal has been reduced.

Response to reacting agents: Students' explained chemical reactions or changes as something that happens to a substance as a result of some responses towards other chemical substances or other kind of agents such as the surroundings, air, heat, and light. These agents were assumed to be causing the chemical substances to change. In other words, the changes, regardless of whether they are physical changes or chemical changes, happen in the presence of or via exposure to the reaction agents. Their assumption was that a chemical reaction is a response of reactants towards agents acting on them.

Interaction between substances: This idea involved more than one substance reacting, but neither of the reacting substances causes the reaction. Students' perceived chemical reactions as obtaining the product from a certain ingredient– like a recipe used in the making of a product, more than one chemical substance is needed for the reaction to happen. Students' using this notion considered the dissolution of sugar and salt as a chemical reaction.

Formation of new substances: A common idea about chemical reactions among Diamono senior high school form 2 students is the production of new substances, which are chemically different from the initial substances. Some other students' shared this notion, but saw it rather differently in terms of how the new substances are formed. Students' understand that, in chemical reactions, the substances formed are new substances. Some students' described the formation of the new substances at the macro level, where the formation of the new substance is merely a transformation from one substance to another. At the submicro level, the students related the formation of new substances to change in chemical bonding, transfer of electrons, change of oxidation number, and chemical composition. A chemical reaction is when either a compound or element is formed from its constituent elements. In ice melting, only involve a change of state as in from water to ice or ice to water, I don't feel it is a chemical reaction, just change of state (A physical change). There is no new product. It is only the state is changed.

Students' commonly failed to differentiate between chemical reactions and physical changes, when solely relying on this idea that new substances formed in chemical changes. Dissolution, for example, was considered as a chemical reaction, because some students' assumed that a solution or even heat energy is a new product formed from combining sugar with water or salt with water. For such students', salt and water, there are two substances mixed together, they will produce new substances.

Submicro changes: Some of the students classified chemical phenomena in terms of changes that happened at the submicro level. Examples of which included modification of chemical bonding, transfer of electron(s), change in oxidation state, and chemical compositions.

Students' acknowledged that there are changes in chemical structures, chemical properties, and energy. Some of these students' who understand that chemical reactions involve changes at the submicro level, also considered that dissolution of salt and sugar in water as a chemical reaction. It is chemical reaction because there is change in terms of the initial structure of the substance.

The Researcher also asked students' the following questions in order to test their notion about chemical reactions.

Researcher: **What happens if wood burns in a fire?**

Students' response: Burning of wood is a chemical reaction. New substances are formed. Wood reacts with oxygen forming 'wood oxide' (or carbon dioxide, etc.). New substances can be identified due to their properties. Particles from wood change into different particles. Total mass of the products: is bigger, equals the mass of reactants is smaller.

Researcher: **What happens if a spoon of salt is put into a glass of water?**

Students' response: Dissolution of salt in water is a physical change. The particles do not change. Particles are still there, but, the particles are too small to be seen. The particles move away from each other. They are distributed between the water particles. The movement of water particles is the driving force for dissolution.

Dissolution of salt in water is a chemical reaction. A new substance is formed. Salt and water particles combine into new particles.

Researcher: How do you explain the phrase 'the water became salty"?

Students' response: A new substance is formed. The salt particles are distributed within the water particles.

Researcher: **What happens if a cake is baked in an oven?**

Students' response: Baking a cake is a chemical reaction. New substances are formed which can be characterised by their new properties. A change in the particles takes place. Baking a cake is a physical change. The only change is a change in the state of matter (from liquid to solid).

Activity 2: Examples of chemical reaction

Researcher: **Give some examples of chemical reactions**

Students' response: Dissolving and changing of physical state as chemical reactions, burning of a candle as melting, melting of ice, dissolution of salt and water, rusting, photosynthesis and combustion.

Summary of Findings from lesson 1

Students' viewed dissolving and changing of physical state as chemical reactions. Students' also considered the burning of a candle as melting. Again, chemical reactions are perceived by students' as a process of mixing of substances or changes in physical characteristics, that is morphological modification such as change in shape, texture, and colour, whereby the initial substance(s) is/are thought to be unchanged. Students' thought chemical reaction happen without manipulation. Students' seemed aware that changes in physical properties were related to changes of chemical substances. Students' perceived chemical reactions or changes as something that happens to a substance as a result of some responses towards other chemical substances or other kind of agents such as the surroundings, air, heat, and light.

Finally, students' are unwilling to accept that products in chemical reactions are actually new substances produced from the initial substance(s).

Based on the above findings from lesson one (1), the mental model constituted by the students' was synthetic mental models (model C). These are students' ideas, which seem to be based on the scientific idea but include some erroneous assumptions or ideas (i.e., the alternative conceptions). It is a mixture or integration of children's initial mental models (model A) and scientific models (model B), which is still embedded in their naive theory.

4.3 Report on lesson 2

Topic: Types of Chemical Reactions

Objectives: After studying this, students' should be able to:

1. State some types of chemical reaction
2. classify some chemical phenomena into the reaction types

Relevant Previous Knowledge: Students' know what chemical reaction is, from their previous lesson. They can also define chemical reaction in different ways and state some examples of chemical reactions.

Activity 1: Types of chemical reaction

Researcher: **State some types of chemical reactions you know.**

Students' response: Synthesis, decomposition, single displacement, double displacement, redox, complexation, acid-base reaction, precipitation, solid state reaction, photochemical reactions, catalysis, substitution, addition and elimination, biochemical reactions etc.

Activity 2: Classification of some chemical phenomena into the reaction types

The Researcher asked students' to state the types of chemical reactions they know through questions and answers. The students' mentioned the types as Synthesis, Decomposition, single displacement, double displacement, redox, complexation, acid-base reaction, precipitation, solid state reaction, photochemical reactions, catalysis, substitution, addition and elimination, biochemical reactions reactions.

The Researcher then gave students' some chemical phenomena to classify them into the types of chemical reactions. The chemical phenomena used included: Rusting, Ice melting, Dissolution of salt and sugar in water, Lead iodide precipitation, Zinc-acid reaction, Combustion of butane, and Chromate-dichromate equilibrium.

Researcher: **Classify the following phenomenon into the following Chemical phenomena and chemical reaction types:**

Redox, Melting, Dissolution, Double displacement, Single displacement, Combustion, Double displacement and acid-base, and Redox in equilibrium

Students' response:

Rusting……………………………….Redox

Ice melting……………………………Melting

Dissolution of salt and sugar in water………………..Dissolution

Lead iodide precipitation…………………………….. Double displacement

Zinc-acid reaction……………………………………. Single displacement

Combustion of butane……………………………….Combustion

An endothermic reaction……………………………… Double displacement and Acid-base

Chromate-dichromate equilibrium……………………….Redox

Summary of Findings from lesson 2

Students' were confused about the composition of water when introduced to synthesis reaction.

Students' could identify the reaction for the oxidation of iron written in formulas as a synthesis or addition reaction; but when confronted with a written scenario, a large portion of the students' identified that same situation as a decomposition reaction. Again, students' also had it in their minds that in neutralisation, the alkali breaks down the acid and stops the acid from "working", only acids are corrosive, bases are not. Students' also had it in their minds that, in neutralisation reaction, only common salt (sodium chloride) is formed.

Majority of the students' saw chemical reaction as the production of new substances, which are chemically different from the initial substances.

The type of mental model expressed by students' was the synthetic mental model. When children are exposed to scientific information about a particular phenomenon, they try assimilating the information into their naive theoretical framework. The end results of this assimilation form what is called synthetic mental model. In other words, a synthetic model is a mixture or integration of children's initial mental models and scientific models, which is still embedded in their naive theory.

4.4 Report on lesson 3

Topic: Chemical Equations

Objectives: After studying this, students' should be able to:

1. Define chemical equation
2. Give at least four examples of formulae equations

3. Determine the reactants and products of a given chemical equations
4. Explain what subscripts and coefficients are in a chemical equation

Relevant Previous Knowledge: Students' can state the first twenty elements on the periodic table. They can also write the chemical symbol for each element stated for the first twenty elements on the periodic table.

Activity 1: Definition of chemical equation

The Researcher asked students' about their notion of chemical equation through questions and answers.

Researcher: ***What is a chemical equation?***

Students Response:

1. A shorthand representation of a chemical reaction (change) using symbols.
2. Chemical equations have been described as 'an essential part of the common language of scientist.

Researcher: Students' were given Magnesium Oxide and Sodium Chloride to write the proper chemical equation.

Response from students':

$Mg + O_2 \longrightarrow MgO$

$Na + Cl_2 \longrightarrow NaCl$

Results indicated that most of the students' were able to answer the question at a macroscopic, microscopic and symbolic level for magnesium oxide and sodium chloride. Most of them were capable of explaining both compounds and their given answers are relatively aligned with the scientific concept. However, majority of them failed to write an appropriate chemical equation to show the formation of MgO and

NaCl. Two mistakes were identified: *that they were not able to write a balanced chemical* equation and *they did not know how to differentiate between chemical equations and chemical formulae*.

Activity 2: Examples of formulae equations

The Researcher asked students' to give some examples of formula equations they know.

Students' Response:

1. $Na_{(s)} + Cl_{2\,(g)} \rightarrow NaCl_{(g)}$,
2. $H_2 + O_2 \longrightarrow H_2O$
3. $Fe + S \rightarrow FeS$
4. $Na + O_2 \rightarrow NaO$
5. $Na + HCl \rightarrow NaCl + H$
6. $K_2 + O_2 \rightarrow KO_2$
7. $Na + H_2O \rightarrow NH_2O$
8. $C + O \rightarrow CO_2$
9. $Ca_{(s)} + O_{2(g)} \rightarrow CaO_{(s)}$
10. $Ca(OH)_{2(l)} + CO_{2(g)} \rightarrow CaCO_{3(s)} + H_2O_{(l)}$

Activity 3: Reactants and products in a given chemical equation

The Researcher gave students' the equation below and asked them to state the reactants and the product.

$$A + B \longrightarrow AB$$

Response from students':

1. **A** is a reactant
2. **B** is a product
3. **AB** is both reactant and product combined

The Researcher also gave students' the equation below and asked them to state the reactants and the products.

$$\mathbf{AB + CD \longrightarrow AD + CB}$$

Response from students':

1. **AB** is reactant
2. **CD** is the product
3. **AD** is also a reactant
4. **CB** is also a product

Activity 4: Definition of subscripts and coefficients in a chemical equation

The Researcher gave students' a chemical equation and asked them to state both the subscripts and coefficients.

Researcher: Indicate the subscripts and coefficients in the chemical equation below

$$\mathbf{2H_2}_{(g)} + \mathbf{O_2}_{(g)} \rightarrow \mathbf{2H_2O}_{(g)}$$

Response from students':

The students' said O_2 (the diatomic form of oxygen) and 2O (two atoms of oxygen), are identical. They assigned the 2 in both diatomic and two atoms of oxygen as subscript and coefficient.

Summary of Findings from lesson 3

When some chemical symbols and formulas were used, such as Cu(s), $H_2O_{(l)}$, and $Cl_{2(g)}$, students' responses indicated that a majority of them confused atoms with molecules. Students' held an additive model of molecules and stated that a water molecule contained a unit of hydrogen gas, H_2. Some students' viewed $H_2O_{(l)}$, and $Cl_{2(g)}$ as representations of one particle without the conception of atoms or a collection. To them, the use of (l) or (g) could not trigger any descriptions about state of molecules. Even though, most students' were able to recognise these chemical symbols as hydrogen or chlorine, they relied on their intuitive mental models of atoms and molecules to make explanations or descriptions about these representations.

Moreover, when students' see an equation, such as $C_{(s)} + O_{2(g)} \longrightarrow CO_{2(g)}$, they interpret it as a composition of letters, numbers and lines rather than a process of bond formation and breaking.

All the three types of mental models stated by the Researcher were exhibited by the students'. Some of their responses were initial mental model, mental models that children possess prior to formal learning about a phenomenon. Other responses also indicated scientific mental models, mental models that are consistent with scientific models and finally, synthetic mental models, a mixture or integration of children's initial mental models and scientific models, which is still embedded in their naive theory.

4.5 Report on lesson 4

Topic: Word equation

Objectives: After studying this, students' should be able to:

1. Define word equation

2. Give at least four examples of word equation
3. Write word equation into formula equation

Relevant Previous Knowledge: Students' can write formula equations for some chemical reactions from their previous lesson.

Activity 1: Definition of word equation

The Researcher through questions and answers helped students' to come out with the definition of word equation as:

A chemical reaction expressed in words rather than chemical formulas.

Activity 2: Examples of word equation

The Researcher asked students' to state some examples of word equation they know.

Response from students'

1. Hydrogen gas + Oxygen gas

2. Carbon dioxide + water

3. Sodium + Chlorine

4. Carbon + Oxygen

5. Magnesium + Oxygen

The Researcher again asked students' to write the word equation for the reaction between calcium and chlorine to form a product.

Response from students'

Calcium + Chlorine $\longrightarrow$ Calcium chlorine

Students' were again given Magnesium Oxide and Sodium Chloride to write the proper chemical equation.

Response from students'

Magnesium + Oxygen $\longrightarrow$ Magnesium oxygen

Sodium + Chlorine $\longrightarrow$ Sodium chlorine

Majority of them failed to write an appropriate chemical equation to show the formation of MgO and NaCl.

Activity 3: Writing of word equation into formula equation

The Researcher asked students' to translate or write the word equations below into formula equations:

1. Hydrogen gas + Oxygen gas $\xrightarrow[\text{100kPa}]{\text{at } 25^{o}\text{C}}$ Steam
2. Carbon dioxide + water $\xrightarrow[\text{Chlorophyll}]{\text{sunlight}}$ Glucose + oxygen
3. Sodium + Chlorine $\longrightarrow$ Sodium chloride
4. Carbon + Oxygen $\longrightarrow$ Carbon dioxide
5. Magnesium + Oxygen $\longrightarrow$ Magnesium oxide
6. Carbon monoxide + Iron oxide $\longrightarrow$ Iron + Carbon dioxide
7. Copper + Sulphur $\longrightarrow$ Copper sulphide
8. Hydrogen + Oxygen $\longrightarrow$ Water
9. Methane + Oxygen $\longrightarrow$ Carbon dioxide + Water
10. Iron + Oxygen $\longrightarrow$ Iron (III) Oxide

Response from students'

1. $H_{2(g)} + O_{2(g)} \longrightarrow H_2O_{(g)}$
2. $CO_2 + H_2O \longrightarrow C_6H_{12}O_6 + O_2$
3. $Na + Cl_2 \longrightarrow NaCl$
4. $C + O_2 \longrightarrow CO_2$
5. $Mg + O_2 \longrightarrow MgO$
6. $CO + Fe_2O_3 \longrightarrow Fe + CO_2$
7. $Cu + S \longrightarrow CuS$
8. $H + O_2 \longrightarrow H_2O$
9. $CH_4 + O_2 \longrightarrow CO_2 + H_2O$
10. $Fe + O_2 \longrightarrow Fe_2O_3$

Summary of Findings from lesson 4

Many students' were confused on how to write or complete word equations for chemical reactions. Chemical names seemed somewhat arbitrary to students'. Students' were confused about the differences between chemical equations and chemical formulae. Scientific mental models were constituted by the students'. Scientific mental models can be considered as mental models that are consistent with scientific models.

4.6 Report on lesson 5

Topic: Balancing Chemical Equations

Objectives: After studying this, students' should be able to:

1. Define balanced chemical equation
2. Balance chemical equations for a given chemical reactions

Relevant Previous Knowledge: Students' can write both formula and word equations for chemical equations and reactions. They can also write chemical equations for some chemical reactions.

Activity 1: Definition of balanced chemical equation

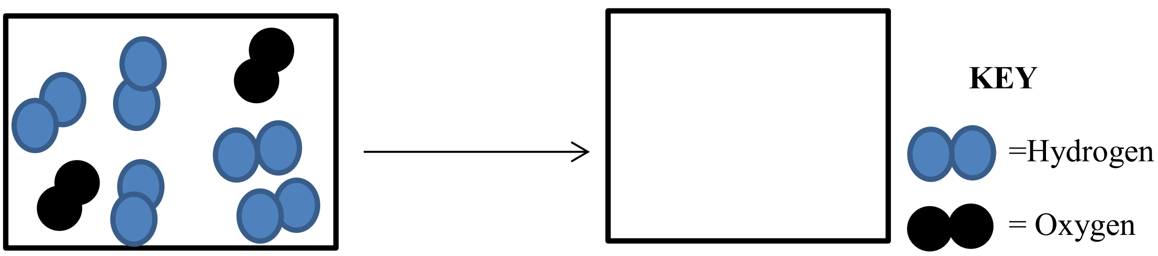
The Researcher asked students' about their notion of balanced chemical equation through questions and answers.

Researcher: **What is a balanced chemical equation?**

Students' response: A balanced chemical equation is an equation in which the total number of atoms of each element on the left hand side is equal to the total number of the same atoms on the right hand side.

Balancing Chemical Equations

Researcher: The Researcher introduced students' to balancing chemical equations by given them series of questions. For example, they were given questions regarding students' mental model of simple chemical reactions that required the students' to use their mental model in transforming chemical phenomena to verbal form and from verbal form to mathematical form (calculations), to interpret the sub-micro visual image of a simple reaction with reactant and the product available in the box.



For the reaction shown above, the Researcher helped students' to draw the correct number of each molecule after the reagents have been converted into a product.

Students' were able to draw the correct number of each molecule after the reagents have been converted into a product but could not write the correct balanced equation for the reaction.

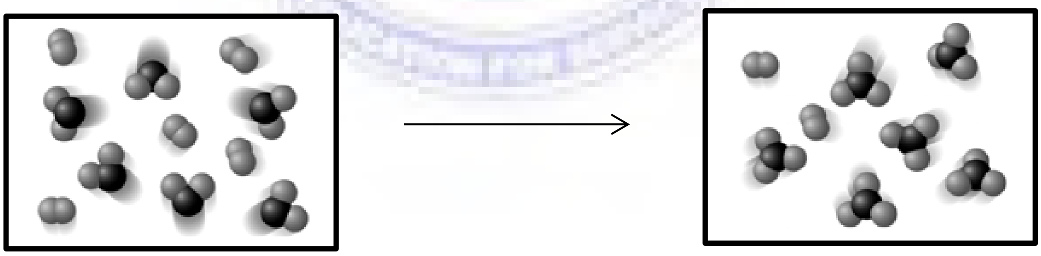
They wrote the balanced equation as: $H_{2\,(g)} + O_{2\,(g)} \rightarrow 2\ H_2O_{\,(g)}$

This shows that students' lack the idea of coefficient in a chemical equation.

Furthermore, the students' were also asked to describe the product of reaction as well as to perform transformation from verbal statement into a sub-micro (visual) diagram by drawing the reactant and product of a given reaction, and to interpret the reaction occurring in a container.

Researcher: The Researcher also asked students' to use the information given to balance the chemical reaction below.

KEY: AB_2  and B_2 



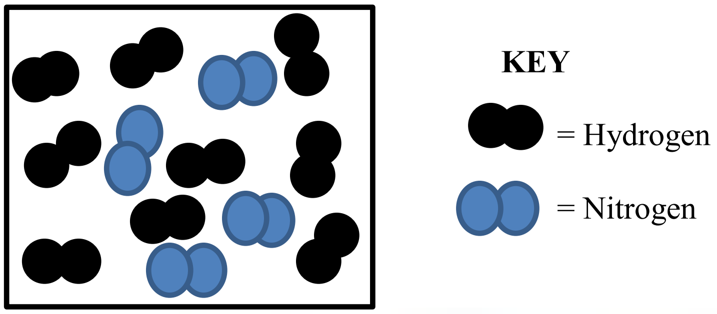
Write a balanced equation for the reaction.

Response from students'

$$2AB_2 + B_2 \longrightarrow AB$$

This also shows that students' lack the idea of coefficients and subscripts in a chemical equation.

Researcher: Nitrogen, N_2, and hydrogen, H_2, react to form ammonia, NH_3. Consider the mixture of N_2 and H_2 shown in the diagram.



Write a balanced equation for this reaction.

Students' response:

Nitrogen gas + Hydrogen gas $\longrightarrow$ Ammonia

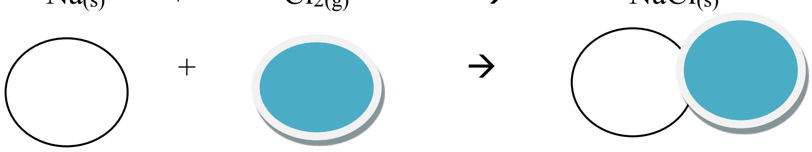
$N_2 + 3H_2 \longrightarrow NH_3$

Students' had difficulties in understanding the meaning of formula subscripts and equation coefficients; for instance, students' tend to change the subscripts while balancing reaction equations. Students' considered balancing chemical reactions as mainly mathematical manipulations of symbols without much insight in the chemical meaning. For instance, students' considered $3H_2$ as six linked atoms. Many students' struggle with balancing equations because they do not understand the concepts behind the process.

Researcher: Write the balanced chemical equation between sodium and chlorine atoms to form sodium chloride.

Response from students'

$Na_{(s)} \quad + \quad Cl_{2(g)} \quad \rightarrow \quad NaCl_{(s)}$



Not balanced

Explanation: Reactants are 1Na and 2Cl; product is 1Na atom and 1Cl atom.

Students' were able to write the correct chemical equation for the reaction but could not write the correct balanced chemical equation. Students' lack the idea of coefficient in balancing chemical equations.

Summary of Findings from lesson 5

Students' thought balancing chemical equations is like balancing an account ledger or solving for a variable in an algebra problem, and they ultimately do not comprehend the reasons for balancing chemical reactions. They solve the problems through a rote process. Students' tend to change both subscripts and coefficients in balancing chemical equation. Students' considered balancing chemical reactions as mainly mathematical manipulations of symbols without much insight in the chemical meaning. They lacked the idea of conservation of mass. Many students' perceive the balancing of equations as a strictly algorithmic (plug-and-chug). Students' tend to change the subscripts while balancing reaction equations.

Finally, most students' had it in their minds that all coefficients are whole numbers. So when introduced to fractional coefficients, they find it difficult to grasp that concept by multiplying every coefficient with a common number to make them whole, typically the denominator of the fractional coefficient for a reaction with a single fractional coefficient.

The mental model constituted by the students' was the initial mental model. Initial mental models are mental models that children possess prior to formal learning about a phenomenon.

4.7 Discussion

Research question 1: *How will the determination of the types of alternate conceptions improve students' understanding of chemical phenomena?*

From the observation made, the Researcher has observed that Integrated Science and Chemistry students' in the senior high schools in Ghana appear to be unable to answer questions when it comes to chemical reactions and balancing chemical equations correctly. Most of their wrong answers revealed specific misconceptions which might be from their preconceptions about the topics. Most of their wrong answers revealed specific misconceptions which needed corrections.

In answering this question, the information gathered was based on conceptual understanding of some chemistry concepts. The Classroom interactions that occurred between the Researcher and the students' were analysed.

The Researcher asked students' about their notion of chemical reaction through questions and answers. The various responses from the students' exposed their mental models of chemical reactions and balancing chemical equations. The students' defined chemical reaction in seven different ways as:

Natural occurrence: Some of the participants considered a chemical reaction to be a natural occurrence, happening without manipulation. In the thinking of these participants, the changes that substances undergo in the surroundings such as rusting and ice melting, are part of nature. What they knew was that in our air, there is oxygen, everywhere, even here where we are sitting, except in vacuum. This thing is natural phenomenon in the world.

Change of chemical substances: Students' with this attribute considered a chemical reaction is evident when any change happens to any chemical substance. They also considered that any chemicals they know of will undergo changes or chemical reactions. Ice melting (which is a physical change) is assumed to be a chemical reaction here purely because it undergoes some changes, which indicates a lack of understanding of the chemical change idea. Substances change from one state to other state through a chemical reaction. The substance changes into a different form. But it is not necessary change in terms of its content.

Change in physical properties: Some students presumed that any change is a chemical reaction, and looked for changes in the physical appearance of materials such as colour and density, all which they see as characteristics of chemical reactions. However, other students seemed aware that changes of physical properties are related to changes of chemical substances. For chemical reactions, we know it when there is change in colour. We look at its colour change.

Response to reacting agents: Students' explained chemical reactions or changes as something that happens to a substance as a result of some responses towards other chemical substances or other kind of agents such as the surroundings, air, heat, and light. These agents were assumed to be causing the chemical substances to change. In other words, the changes, regardless of whether they are physical changes or chemical changes, happen in the presence of or via exposure to the reaction agents. Their assumption was that a chemical reaction is a response of reactants towards agents acting on them. The iron rusting is caused by acid rain. The surface of the iron is exposed to the surroundings like rain, water, and the surroundings, that's what causes the iron rust. The element in iron metal reacts with the element in the water and oxygen. The oxygen makes the iron undergoes reduction. There is something causes it to happen. Chemical reaction is something that makes something change.

Interaction between substances: This idea involved more than one substance reacting, but neither of the reacting substances causes the reaction. Students' perceived chemical reactions as obtaining the product from a certain ingredient– like a recipe used in the making of a product, more than one chemical substance is needed for the reaction to happen. Students' using this notion considered the dissolution of sugar and salt as a chemical reaction.

Formation of new substances: A common idea about chemical reactions among Diamono senior high school form 2 students is the production of new substances, which are chemically different from the initial substances. Some other students' shared this notion, but saw it rather differently in terms of how the new substances are formed. Students' understand that, in chemical reactions, the substances formed are new substances. Some students' described the formation of the new substances at the macro level, where the formation of the new substance is merely a transformation from one substance to another. At the submicro level, the students related the formation of new substances to change in chemical bonding, transfer of electrons, change of oxidation number, and chemical composition. A chemical reaction is when either a compound or element is formed from its constituent elements. In ice melting, only involve a change of state as in from water to ice or ice to water, I don't feel it is a chemical reaction, just change of state (A physical change). There is no new product. It is only the state is changed.

Students' commonly failed to differentiate between chemical reactions and physical changes, when solely relying on this idea that new substances formed in chemical changes. Dissolution, for example, was considered as a chemical reaction, because some students' assumed that a solution or even heat energy is a new product formed from combining sugar with water or salt with water. For such students', salt and water, there are two substances mixed together, they will produce new substances.

Submicro changes: Some of the students classified chemical phenomena in terms of changes that happened at the submicro level. Examples of which included modification of chemical bonding, transfer of electron(s), change in oxidation state, and chemical compositions.

Students' acknowledged that there are changes in chemical structures, chemical properties, and energy. Some of these students' who understand that chemical reactions involve changes at the submicro level, also considered that dissolution of salt and sugar in water as a chemical reaction. It is chemical reaction because there is change in terms of the initial structure of the substance.

When the Researcher asked students' about what happens if wood burns in a fire,

The response from the students' revealed some alternate conception about chemical reactions. The students' said burning of wood is a chemical reaction. New substances are formed. Wood reacts with oxygen forming 'wood oxide' (or carbon dioxide, etc.). New substances can be identified due to their properties.

The student' also said that dissolution of salt in water is a physical change when the Researcher asked them about what happens if a spoon of salt is put into a glass of water?

They said particles do not change. Particles are still there, but, the particles are too small to be seen.

Students' were presented three chemical phenomena: rusting, ice melting, and dissolution of sugar and salt. Subsequently, the students' were asked to identify whether the phenomena were chemical reactions or physical changes and explain what they think happened in the events. Most of the students' easily identified rusting as a chemical reaction, some of the students' also considered the dissolution of salt and sugar to be a chemical reaction. Surprisingly, a fair number of the students' also considered ice melting as a chemical reaction.

Based on the various responses provided by the students' during the lessons, it is clear that the students' had an alternate misconception of chemical reactions. The findings of lessons 1 supported that.

Classification of Students' Mental Models of Chemical Reactions

This study also sought to understand students' mental models of chemical reactions by addressing the second research question.

Research question 2: *How can the classification of students' alternate conceptions help them to understand the concept of chemical reactions?*

To assist with identification of different types of students' mental models, the attributes of these models were classified into three different categories, namely *initial*, *synthetic,* and *scientific.* The initial attributes are students' ideas or constructs related to a component in a given target system of chemical reactions, which were not based on any scientific view about chemical reactions. Conversely, scientific attributes are students' ideas which seem to be based on scientific knowledge, and which are considered consistent with scientific views. Finally, synthetic attributes are students' ideas, which seem to be based on the scientific idea but include some erroneous assumptions or ideas (i.e., the alternative conceptions).

This attributes-based classification identified three distinct mental models of chemical reactions expressed by students'. The first type of mental model called Model A, is considered mainly non-particulate, with an absence of the kinetic theory of particles and chemical bonding. Model A mainly consisted of the *initial* attributes for all of the target systems of chemical reactions. The second type of mental model, Model B was based either on the attributes related to the kinetic theory of particles or attributes related to chemical bonding. This type of mental model consisted of a mixture of initial, synthetic, and scientific attributes. Finally, Model C was identified as a mental model type comprising attributes related to both kinetic theory of particles and chemical bonding, which were considered consistent with the scientific views of chemical reactions.

Although students' mental models were categorised into different types, it is interesting that some of the attributes were common to all types of the mental models. For example, in terms of students' understanding of chemical reactions, almost all of the attributes were present in all types of mental model. The obvious differences between Model A and Model C were the absence of the attribute, *submicro changes* in Model A and that of *expected natural occurrence* in Model C. In the conservation of mass component, most of the initial and synthetic attributes were identified in all types of mental model. However, the dominant attribute held by students was identified as the *closed system,* which occurred mostly in Model B and Model C. The only clear distinction between Model A and Model B compared with Model C was the presence of the *rearrangement of atoms* attribute in Model C.

Based on the various responses students' gave about their notion of chemical reaction, the Researcher classified their alternate conceptions as shown in table 1 below.

Table 1: Classification of Students' Mental Models Attributes of Chemical Reactions

Component	Initial attributes	Synthetic attributes	Scientific attributes
Composition	Expected natural Occurrence	Response to reacting agents	Submicro change
	Change of chemical substances	Formation of new substances	
	Change in physical properties	Interaction between substances	
Conservation of mass	Dependent on the physical state	Closed system	Rearrangement of atoms
	More substances Formed		
	Gas properties		

The Researcher also based on the different definitions provided by the students' to come out with the types of students' mental models of chemical reactions as shown in table 2 below.

Table 2: Type of Students' Mental Models of Chemical Reactions

Model	Description
A	Chemical reactions are mainly described as the response of chemical substances towards other reacting agents such as other chemical substances, heat energy, air and surroundings. Reactions are described at the macro level. Energy change in chemical reactions is based on energy gain-loss reasoning. Reaction is driven by the reactants.
B	Chemical reactions are sometimes described as changes that happen at the submicro level. The process of chemical reactions is described based on either kinetic theory of particles or chemical bonding. Energy change in chemical reactions is based on the idea that energy transfer occurs between a chemical system and the surroundings. Chemical reactions are driven by various non-energy based factors.
C	Chemical reactions are described as changes happen at the submicro level. Reactions based on kinetic theory of particles and chemical bonding. Energy change in chemical reactions is explained as two ways energy transfer between a chemical system and the surroundings. Transfers of energy are due to the breaking and formation of chemical bonds. Change of temperature is related to the net energy transfer. Chemical reactions are driven by various factors.

The Researcher being able to classify students' mental model attributes of chemical reaction, and grouped them as model A, model B, and model C as shown above would help to improve students' understanding of chemical concepts.

Research question 3: *How will the teaching intervention help students' to understand concepts in chemistry?*

Students' mental models analysed by acquisition of mental models test questions on mental models can be seen in the students' ability to interpret sub-micro drawing transformation of molecular and chemical phenomena on one level to another level.

The questions regarding students' mental model of simple chemical reactions required the students' to use their mental model in transforming chemical phenomena to verbal form and from verbal form to mathematical form (calculations), to interpret the sub-micro visual image of a simple reaction with reactant and the product available in the box as seen in the report. Furthermore, the students' are also asked to describe the product of reaction as well as to perform transformation from verbal statement into a sub-micro (visual) diagram by drawing the reactant and product of a given reaction, and to interpret the reaction occurring in a container.

The classification of the attributes of students' mental models would help the Researcher to develop strategies to help students' understand chemical concepts.

The teaching intervention would be Multiple Representation Method (MRM). This method would enable students' to use their mental model in transforming chemical phenomena to verbal form and to interpret the sub-micro visual image of a simple reaction with reactant and the product available.

Research question 4: *How will the teaching intervention influence students' learning outcomes?*

Based on the analysis of students' mental models, it seems like the students' mental model of chemical reaction stoichiometry with various questions from interpretation down to verbal-to-symbolic and verbal to-visual transformations (sub-micro diagram) and vice versa indicates significant differences. Students who were initially unable to write reaction equation by directly translating the sub-micro image were able to directly interpret the reaction equation from sub-micro image as well as solve a balanced reaction at the same time after adopting the learning model based on multiple representations. These results suggest that after the implementation of learning by using multiple representation method, students' would be able to cultivate mental models in the face of external representation of macro and sub-micro level, when compared to the prior implementation of learning.

During the implementation of the intervention, students' were made to work individually. The Researcher went round to help those with difficulties. The Researcher put students' into groups with each group assigned a group leader. Students' were allowed to jot down points during lessons. Students' came together to share ideas in order to come out with solutions to the assignments given to them by the Researcher. The Researcher made each group to present their report. Every student was made to do presentation based on their group report. Students' took active part in the group work as they were called to present their report.

Students' Learning Progress Monitoring Form (SLPMF) was also provided. This form was used to collect data on students' progression in the classroom activities during the intervention. The form consisted of the name of student on the vertical column, exercise number and score on the horizontal column. At the end of each lesson the Researcher marked the exercise and recorded the marks scored against each student. The sum total and average scores were then calculated for all the students as well as the individual student for each lesson. The Researcher figured out excellent, good and average students and rewarded them. Individual scores were announced and students who improved over the exercises were rewarded. This was done to recognise individual accomplishment and to encourage the students' to learn hard. This had improved students' learning outcomes as they worked individually and also in groups. The Researcher finally scored each group by awarding marks to group members. This made students' punctual in class and lateness was also avoided.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Overview

In this chapter the summaries of the mental models of the students' of the study have been documented. There were ten major findings that emerged out of the lessons taught. In this study, it was observed that though only five lessons were reported, there was quite an appreciable gain in students' learning and answers to questions. Conclusions, recommendations and suggestions were made based on the findings for further research work.

5.2 Summary of findings

There were ten main findings in this study which spanned five lessons on chemical reactions and balancing chemical equations. The following were the major findings that emerged from the study:

1. Students' thought chemical reaction happen without manipulation and seemed aware that changes of physical properties are related to changes of chemical substances.
2. When some chemical symbols and formulas were used, such as $Cu_{(s)}$, $H_2O_{(l)}$, and $Cl_{2(g)}$, students' responses showed that they held an additive model of molecules and stated that a water molecule contained a unit of hydrogen gas, H_2. Students' viewed $H_2O_{(l)}$, and $Cl_{2(g)}$ as representations of one particle without the conception of atoms or a collection. To them, the use of (l) or (g) could not trigger any descriptions about state of molecules.
3. Chemical names seemed somewhat arbitrary to students'.

4. Students' thought balancing chemical equations is like balancing an account ledger or solving for a variable in an algebra problem, and they ultimately do not comprehend the reasons for balancing chemical reactions.
5. Students' considered balancing chemical equations as mainly mathematical manipulations of symbols without much insight in the chemical meaning.
6. Even though, students' were able to recognise chemical symbols as hydrogen or chlorine, they relied on their intuitive mental models of atoms and molecules to make explanations or descriptions about these representations.
7. Moreover, when students' see an equation, such as $C_{(s)} + O_{2(g)} \longrightarrow CO_{2(g)}$, they interpret it as a composition of letters, numbers and lines rather than a process of bond formation and breaking.
8. Students' tend to change both subscripts and coefficients and also had it in their minds that all coefficients are whole numbers when balancing chemical equations.
9. Students' have difficulty distinguishing chemical changes from physical changes, fail to recognise conservation of mass in chemical systems, and are limited in describing chemical changes even at the macro level. These students' also struggled to provide an explanation of how chemical reactions happen at the submicro level. This finding suggests that these students' mental models are non-particulate in nature and comprise a transmutation view of chemical reactions, a model which possesses little capacity for explaining chemical changes.
10. Chemical reactions were perceived by the students' as a process of mixing of substances or changes in physical characteristics, that is morphological

modification such as change in shape, texture, and colour, whereby the initial substance(s) is/are thought to be unchanged.

5.3 Conclusion

On the basis of the results obtained in the study, it is concluded that to improve better teaching strategies and learning environments, it is important to know students' alternative conceptions and the type of those conceptions. When a mental model is composed in students' mind, it is not easy to change it in the higher levels. Although, the mental models of students' in this present study was based on the particle model of matter, there were indications that their mental models may be non-particulate mental models. This is consistent with the findings that students' have difficulty distinguishing chemical changes from physical changes, fail to recognise conservation of mass in chemical systems, and are limited in describing chemical changes even at the macro level. These students' also struggled to provide an explanation of how chemical reactions happen at the submicro level. Taken together, these findings suggest that these students' mental models are non-particulate in nature and comprise a transmutation view of chemical reactions, a model which possesses little capacity for explaining chemical changes.

Students' also had it in their mind that balancing chemical equations is like balancing an account ledger or solving for a variable in an algebra problem, and they ultimately do not comprehend the reasons for balancing chemical reactions. They solve the problems through a rote process. Students' considered balancing chemical reactions as mainly mathematical manipulations of symbols without much insight in the chemical meaning. They lacked the idea of conservation of mass. Many students' perceive the balancing of equations as a strictly algorithmic (plug-and-chug). Students' tend to change the subscripts while balancing reaction equations.

Holding a non-particulate view of matter in students' mental models likely their mental models development concerning the concept of matter. This is because chemistry, in this era, is a study of matter that is mainly based on the idea that matter is atomic and without this fundamental understanding of the composition of matter, chemistry would be intellectually amorphous. This gap in their understanding also implies that teaching a variety of chemical reaction types, such as acid and alkali, metal and non-metal reactions, metal compounds, and other physical properties of matter such as solubility and air pressure, are likely to be futile because these phenomena are best described and understood from the particulate perspective. Besides that, with the non-particulate view in their mental models may also delay the mental models development in terms of chemical kinetics, which is another important aspect of chemical reactions.

The preference for this model could perhaps lie in the straightforwardness in the explanation of energy change in chemical reactions. Energy was viewed as a quasi-material that can be added, removed, or stored in matter. The core attribute of students' mental models at the senior high level of education is considered to be agentive in nature, which has its roots in intuitive knowledge; that is, chemical reactions are viewed as driven or controlled by causal agent(s), including chemical substances and heat energy. When there are more agents present, the faster a reaction goes; heat energy as a causal agent can initiate chemical reactions; the occurrence of chemical reactions depends on the presence of causal agents; and that chemical reactions are reversible when suitable causal agents are present.

5.4 Recommendations

In the light of the findings in this study, the following recommendations are made for science teachers and school administrators:

1. It is recommended that the idea of matter (rather than mere particle) need to be nurtured and become the central underpinning idea in studying and understanding the nature of matter. Students' should also be taught on how to use this model in explaining chemical phenomena (i.e., chemical and physical changes). This emphasis may also then help them integrate the macro and submicro levels of chemistry in their development of understanding of chemical reactions.
2. It is also recommended that, science teachers' should help students' to compare evaporation and hydrolysis of water, whereby a 3-dimensional model could be used to show how the arrangement of water molecules change in evaporation but not the arrangement of hydrogen and oxygen atoms, and how chemical composition of water changes into hydrogen gas and oxygen gas in the hydrolysis of water. Science teachers' should also introduce students' to phases such as solid (s), liquid (l), gas (g), aqueous (aq) and when to use each of them.
3. Science teachers' should teach students' chemical names before introducing them to chemical reactions and balancing chemical equations. By doing that, chemical names would not seem somewhat arbitrary to students'.
4. In order to help students' understand the concept of balancing chemical equations correctly, it is recommended that, teachers' should use both the inspection method and the linear algebraic approach in teaching balancing chemical equations. Teachers' should also teach the students' the importance of balancing chemical equations.
5. Teachers' should also use chemical models in teaching balancing chemical equations.

6. Teachers' need to be aware that the idea of particles such as atoms, molecules, and kinetics, is not readily comprehensible to students' when introducing the topic of chemical reactions and physical changes. Therefore, senior high school students' should be introduced to the particulate idea of matter (including the concepts of atoms and molecules) through more concrete or tangible models (i.e., models with concrete modes of representation) such as 3D models, scale models, and physical simulations that lead to the development of understanding of the nature of models.
7. Teachers' should teach students' interpretation and reading of chemical equations to enable them see chemical equations as a process of bond formation and breaking and not composition of letters, numbers and lines.
8. Science teachers' should introduce students' to both subscripts and coefficient when teaching them balancing chemical equations. This would enable them not to interchange subscripts and coefficients when balancing chemical equations.
9. Science teaching should be geared towards developing students' initial non-particulate mental model of matter using concrete representations (such as concrete models, role-playing, and computer simulations) and encouraging them to apply the particulate model to make sense of their everyday experiences regarding chemical phenomena.
10. Students' holding a non-particulate mental models of matter means they will find it difficult to make sense of the concepts of atoms, atomic structure, electron configuration, and chemical bonding, as well as chemical reactions. Therefore, it is strongly urged that greater focus is made on developing a particulate model of matter (with the introduction of atoms and molecules) as

a component of students' mental models of chemical reactions at the senior high school level. Specifically, this means that senior high school students should be introduced to model-based instruction that encourages them to construct acceptable mental models of particles and link these models with the chemical phenomena and balancing chemical equations.

5.5 Suggestions for Further Research

The participants in this study were students' from SHS 2 who studied science. Therefore, comparison of mental models of chemical reactions and balancing chemical equations among those students' studying chemistry, such as organic, inorganic, physical chemistry, chemical engineering, and also among the practitioners would merit further research. Likewise, a longitudinal inquiry may be of interest in providing insights into how students' mental models of transformations of matter (chemical and physical changes) develop over time.

The findings from this study raised some pertinent issues for the teaching and learning of chemistry in schools. This study suggests that senior high school students' mental models of chemical reactions and balancing chemical equations as well as matter are not well developed, potentially an indication that science education in this particular context failed to help students develop mental models. Therefore, an inquiry investigating the impact of an intervention would be beneficial. For instance, the application of modelling-based instruction that requires students' to learn what a model is, how to use a model, how to construct a model, and how to evaluate the model, would be of interest to science education researchers.

Additionally, this study also found that students' intuitive knowledge of a causal agentive idea of chemical change plays a significant role in students' learning of chemistry. However, this study did not seek to address why and how this notion came to be so strongly embedded in students' cognitive structure. This question may require research from another perspective, such as cognitive psychology and activity theory, looking at the development of knowledge concerning change of matter.

This study examined students' mental models of chemical reactions and balancing chemical equations at the SHS level in Jaman North District in the Brong Ahafo region of Ghana, further studies can be conducted to investigate students' mental models in other topics or disciplines, in urban, in rural, in suburban schools.

REFERENCES

Adbo, K., & Taber, K. S. (2009). Learners' mental models of the particle nature of matter: A study of 16-year-old Swedish science students. *International Journal of Science Education 31*(6), 757-786.

Agung, S., & Schwartz, M. S. (2007). Students' understanding of conservation of matter, stoichiometry and balancing equations in Indonesia. *International Journal of Science Education 29*(13), 1679-1702.

Ali, T. (2012). *A case study of the common difficulties experience by high school students in chemistry classroom in Gilgit-Baltistan(Pakistan).* Khan: Khan University-Institute for Educational Development: 1-13.

Allen, M. (2010). *Misconception in primary science.* New York: Open university press.

Amedahe, F. K. (2002). *Fundamentals of educational research methods.* Cape Coast: University of Cape Coast.

Amoani, K. (2005). *Research methodology and review.* Accra: Pentecost Press.

Annum, G. (2015). *Research instruments for data collection*. Retrieved August 5, 2016, from campus.educadium.com/newmdiart/file.../ugraResearch/.../resinstr

Ary, J., & Razaviet, B. (2002). *Research in education.* London: Wadswork Group.

Atkins, P. (2005). Skeletal chemistry. *Education in Chemistry 42*, 20.

Atkins, P., & Jones, L. (2010). *Chemical principles: The quest for insight.* New York, NY: W. H. Freeman: 38-46.

Austin, H., & Jeffery, S. (2004). *Models that matter.* Bloomington: Indiana University: 29-31.

Ball, D. W. (2011). *Chemical reactions and equations. SPIE Press*. Retrieved July 20, 2016, from http//www.index.html

Barke, H. D., Hazari, A., & Yitbarek, S. (2009). *Misconceptions in chemistry: Addressing perceptions in chemical education.* Berlin Heidelberg, Germany: Springer-Verlag: 21-36.

Barker, V. (2000). *Beyond appearances: Students' misconceptions about basic chemical ideas.* London, UK: Royal Society of Chemistry: 9-29.

Barker, V., & Millar, R. (2000). Students' reasoning about basic chemical thermodynamics and chemical bonding: What changes occur during a context-based post-16 chemistry course? *International Journal of Science Education 22*(11), 1171-1200.

Benzivin, J. (2010). *Models everywhere.* France: University of Nantes.

Bernard, H. R. (2002). *Research methods in anthropology: Qualitative and quantitave methods (3rd ed.).* Walnut Creek, California: Alta Mira Press.

Blaikie, N. (2000). *Designing social research: The logic of anticipation.* Cambridge, UK: Polity Press.

Bliss, J. (2008). Commonsense reasoning about the physical world. *Studies in Science Education 44(2)*, 123-155.

Boo, H. K., & Watson, J. R. (2001). Progression in high school students' conceptualisations about chemical reactions in solution. *Science Education 85*(5), 568-585.

Bogdan, R. C., & Biklen, S. K. (2007). *Qualitative research for education: An introduction to theory and methods(5th ed.).* Boston, MA: Allyn & Bacon.

Boohan, R. (2002). Learning from models, learning about models. In S. Amos, & R. Boohan (Eds.), *Aspects of teaching secondary school: Perspectives on practice*. London, UK: Routledge, Falmer: 117-129.

Boulter, C. J., & Buckley, B. C. (2000). Constructing a topology of models for science education. In J. K. Gilbert, & C. J. Boulter (Eds.), *Developing models in science education*. Dordrecht: The Netherlands. Kluwer: 41-57.

Brewer, W. F. (2003). Mental models. In L. Nadel (Ed.), *Encyclopedia of cognitive science*. London, UK: Nature Publishing Group: 1-6.

Burns, K. J. (2001). Mental models of line drawings. *Perception 30*(10), 1249-1261.

Cakmakci, G. (2010). Identifying alternative conceptions of chemical kinetics among secondary school and undergraduate students in Turkey. *Journal of Chemical Education 87*(4), 449-455.

Castillo, J. J. (2009). *Research population*. Retrieved July 23, 2016, from http://www.experiment-resources.com/research-population.html

Cavallo, A., McNeely, J. C., & Marek, E. A. (2003). Eliciting students' understandings of chemical reactions using two forms of essay questions during a learning cycle. *International Journal of Science Education 25*(5), 583-603.

Cepni, S. (2010). *Introduction to research and studies project.* Trabzon: Celepler Printing.

Chaiklin, S. (2003). The zone of proximal development in Vygotsky's analysis of learning and instruction. In A. Kozulin, B. Gindis, V. S. Ageyev, & S. M. Miller(Eds.), *Vigotsky's educational theory in cultural context*. Cambridge, UK: Cambridge university press. 39-64.

Chamizo, J. (2007). Teaching modern chemistry through 'recurrent historical teaching models'. *Science & Education 16*(2), 197-216.

Chamizo, J. (2013). A new definition of models and modelling in chemistry's teaching. *Science & Education 22*(7), 1613-1632.

Chi, M. T. (2005). Commonsense conceptions of emergent processes: Why some misconceptions are robust. *Journal of the Learning Sciences 14*(2), 161-199.

Chiou, G. L., & Anderson, O. R. (2010). A study of undergraduate physics students' understanding of heat conduction based on mental model theory and an ontology process analysis. *Science Education 94*(5), 825-854.

Chittleborough, G. D. (2004). *The role of teaching models and chemical representations in developing students' mental models of chemical phenomena.* Australia: Curtin University of Technology.

Chiu, M. H., Chou, C. C., & Liu, C. J. (2002). Dynamic processes of conceptual change: Analysis of constructing mental models of chemical equilibrium. *Journal of Research in Science Teaching 39*(8), 688-712.

Clement, J. J., & Steinberg, M. S. (2002). Step-wise evolution of mental models of electric curcuits: A "learning-loud" case study. *Journal of the Learning Sciences 11*(4), 389-452.

Cohen, L., Manion, L., & Morrison, K. (2008). *Research methods in education.* New York, NY: Routledge: 92-104.

Coll, R. K. (2006). The role of models, mental models and analogies in chemistry teaching. In P. Aubusson, A. Harrison, & S. M. Ritchie (Eds.), *Metaphor and analogy in science education.* Dordrecht: Kluwer: 65-77.

Coll, R. K. (2008). Chemistry learners' preferred mental models for chemical bonding. *Journal of Turkish Science Education 5*(1), 22-47.

Coll, R. K., & Lajium, D. (2011). Modelling and the future of science learning. In M. S. Khine, & I. M. Saleh (Eds.), *Models and modelling: Cognitive tools for scientific enquiry*. Dordrecht. The Netherlands: Springer. 3-21.

Coll, R. K., & Treagust, D. F. (2001). Learners' mental models of chemical bonding. *Research in Science Education 31*(3), 357-382.

Coll, R. K., & Treagust, D. F. (2003a). Investigation of Secondary school, undergraduate, and graduate learners' mental models of ionic bonding. *Journal of Research in Science Teaching 40*(5), 464-486.

Coll, R. K., & Treagust, D. F. (2003b). Learners' mental models of metallic bonding: A cross-age study. *Science Education 87*(5), 685-707.

Coll, R. K., France, B., & Taylor, I. (2005). The role of models/and analogies in science education: Implications from research. *International Journal of Science Education 27*(2), 183-198.

Collins, A. (2002). How students learn and how teachers teach. In R. W. Bybee (Ed.), *learning science and the science of learning*. Arlington,VA: NSTA Press. 3-11

Crawford, B. A., & Cullin, M. J. (2004). Supporting prospective teachers' conceptions of modelling in science. *International Journal of Science Education 26*(11), 1379-1401.

Creswell, J. W. (2008). *Educational research: planning, conducting, and evaluating quantitative and qualitative research* (3rd ed.). New Jersey: Upper Saddle River.

Creswell, J. W. (2012). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research (4th ed.).* Boston, MA: Pearson: 3-21.

Dalton, R. M. (2003). *The development of students' mental models of chemical substances and processes at the molecular level.* Australia: National Library of Australia's Trove Service.

David, A. K. (2004). *Writing chemical equations.* Pima: community college.

Davidowitz, B., Chittleborough, G., & Murray, E. (2010). Student-generated submicro diagrams: A useful tool for teaching and learning chemical equations and stoichiometry. *Chemistry Education Research Practice 11*(3), 154-164.

Denscombe, M. (2010). *Ground rules for social research guidelines for good practice.* Berkshire, UK: Open University Press.

Devetak, I., Lorber, E. D., Jurisevic, M., & Glazar, S. A. (2009). Comparing Slovenian year 8 and year 9 elementary school pupils' knowledge of electrolyte chemistry and their intrinsic motivation 10*(4)*. *Chemistry Education Research Practice*, 281-290.

Duit, R. (2009). *Students' and teachers' conceptions and science education*. Retrieved July 25, 2016, from http//www.ipn.uni-kiel.de/aktuell/stcse/stcse.html

Dusick, D. M. (2011). *Writing the delimitations*. Retrieved July 25, 2015, from http//www.bolded.com/delimitations.htm

Ebenezer, J. V., & Fraser, D. M. (2001). First year chemical engeneering students' conceptions of energy in solution processes. *Phenomenographic categories for common knowledge construction. Science Education 85*(5), 509-535.

Ede, A. (2006). *The chemical element: A historical perspective.* Westport, CT: Greenwood Press.

Eilks, I., Moellering, J., & Valanides, N. (2007). Seventh-grade students' understanding of chemical reactions: Reflections from an action research interview study. *Eurasia Journal of Mathematics, Science & Technology Education 3*(4), 271-286.

Espinet, M., Izquierdo, M., Bonil, J., & De Robles, S. L. (2012). The role of language in modelling the natural world: Perspectives in science education. In B. J. Fraser, K. Tobin, & C. J. McRobbie (Eds.), *Second international handbook of science education*. Dordrecht, The Netherlands: Springer: 1385-1403.

Fensham, P. J. (2001). Science content as problematic- Issues for research. In H. Behrendt, H. Dahncke, R. Duit, W. Graber, M. Komorek, A. Kross, et al.(Eds.), *Research is science education- Past, present, and future*. Dordrecht, The Netherlands: Kluwer: 27-41.

Ferrance, E. (2000). *Action research: education themes, national and regional educational laboratory, Brown University*. Retrieved July 20, 2016, from http://www.alliance.brown.edu/pubs/themes_ed/act_research.pdf

Foley, B. J., & McPhee, C. (2008). *Students' attitude towards science using hands-on or textbook based curriculum.* New York, NY: The American Educational Research Association.

Fraenkel, J. R., & Wallen, N. E. (2000). *How to design and evaluate research in education.* McGraw-Hill.

Franco, C., & Colinvaux, D. (2000). Grasping mental models. In J. K. Gilbert, & C. J. Boulter (Eds.), *Developing models in science education*. Dordrecht. The Netherlands: Kluwer: 93-118.

Frigg, R., & Hartmann, S. (2006). Scientific models. In S. Sarkar, & J. Pfeifer (Eds.), *The philosophy of science: An encyclopedia*. New York, NY: Taylor & Francis: 740-749.

Galley, W. C. (2004). Exothermic bond breaking: A persistent misconception. *Journal of Chemical Education 81*(4), 523.

Gentner, D. (2001). Mental models, psychology of . In N. J. Smelser, & P. B. Baltes (Eds.), *International encyclopedia of the social and behavioural sciences*. Oxford. UK: Pergamon: 9683-9687.

Gibbs, G. R. (2007). *Analysing qualitative data.* Los Angeles, LA: Sage.

Giere, R. N. (2004). How models are used to represent reality. *Philosophy of Science 71*(5), 742-752.

Gilbert, J. K., Boulter, C. J., & Elmer, R. (2000). Positioning models in science education and in design and technology education. In J. K. Gilbert, & C. J. Boulter, *Developing models in science education*. Dordrecht, The Netherlands: Kluwer: 3-17.

Gkitzia, V., Katerina, S., & Chryssa, T. (2011). Development and application of suitable criteria for the evaluation of chemical representations in school textbooks. *Chemistry Education Research Practice 12*, 5-14.

Gobert, J. D., & Buckley, B. C. (2000). Introduction to model-based teaching and learning in science education. *International Journal of Science Education 22*(9), 891-894.

Goldberg, D. E. (2007). *Fundamentals of chemistry (5th ed.).* Columbus, OH: McGraw-Hill.

Gomm, R., Hammersley, M., & Foster, P. (2000). *Case study method: Key issues, key texts.* London: Sage Publications.

Greca, I. M., & Moreira, M. A. (2002). Mental, physical, and mathematical models in the teaching and learning of physics. *Science Education 86*(1), 106-121.

Greenbowe, T., & Meltzer, D. (2003). Student learning of thermochemical concepts in the context of solution calorimetry. *International Journal of Science Education 25*(7), 779-800.

Grix, J. (2004). *The foundation of research.* Hampshire, UK: Palgrave.

Guzel, B. Y., & Adadan, E. (2013). Use of multiple representations in developing pre-service chemistry teachers' understanding of the structure of matter. *International Journal of Environmental & Science Education 8*(1), 109-130.

Hafilah, O. (2008). *Kefahaman pelajar tingkatan empat sekolah menengah mengenai ikatan Kimia.* Universiti Teknologi Malaysia (UTM).

Halloun, I. A. (2006). *Modelling theory in science education.* Dordrecht: The Netherlands. Springer.

Harrison, A. G., & Treagust, D. F. (2000a). Learning about atoms, molecules, and chemical bonds: A case study of multiple-model use in grade 11 chemistry. *Science Education 84*(3), 352-381.

Harrison, A. G., & Treagust, D. F. (2000b). A topology of school science models. *International Journal of Science Education 22*(9), 1011-1026.

Hart, C. (2008). Models in physics, models for physics learning, and why the distinction may matter in the case of electric circuits. *Research in Science Education 38*(5), 529-544.

Hatzinikita, V., Koulaidis, V., & Hatzinikitas, A. (2005). Modelling pupils' understanding and explanations concerning changes in matter. *Research in Science Education 35*(4), 471-495.

Haussler, P., & Hoffmann, W. (2003). Intervention study to enchance girls' interest, self-concept, and achievement in physics classes. *Journal of Research in Science Teaching 39*, 870-888.

Henderson, L., & Tallman, J. (2006). *Stimulated recall and mental models.* Lanham, ML: Scarecrow Press Inc.

Herga, N. R., Grmek, M. I., & Dinevski, D. (2014). Virtual laboratory as an element of visualisation when teaching chemical contents in science class. *Turkish Online Journal of Education Technology 13*(4), 157.

Hubber, P. (2006). Students' mental models of the nature of light. *Research in Science Education 36*(4), 419-439.

Jaber, L. Z., & Boujoude, S. (2012). A macro-micro-symbolic teaching to promote relational understanding of chemical reactions. *International Journal of Science Education 34*(7), 973-998.

Jabot, M., & Henry, D. (2007). Mental models of elementary and middle school students in analysing battery and bulb circuits. *School Science and Mathematics 107*(1), 371-381.

Jack, F. R., & Norman, E. W. (2003). *How to design and evaluate research in education (5th Ed.).* Boston: McGraw Hill Publishers.

Johnson, P. (2000). Children's understanding of substances, Part 1: Recognising chemical change. *International Journal of Science Education 22*(7), 719-737.

Johnson, P. (2002). Children's understanding of substances, Part 2: Explaining chemical change. *International Journal of Science Education 24*(10), 1037-1054.

Johnson-Laird, P. N. (2004a). The history of mental models. In K. Manktelow, & M. C. Chung (Eds.), *Psychology of reasoning: Theoretical and historical perspectves*. New York, NY: Psychology Press: 179-212.

Johnson-Laird, P. N. (2004b). Mental models and reasoning. In J. P. Leighton, & R. J. Sternberg (Eds.), *The nature of reasoning*. Cambridge, UK: Cambridge University Press:169-204.

Johnson-Laird, P. N. (2005a). Flying bicycles: How the Wright brothers inventad the airplane. *Mind & Society 4*(1), 27-48.

Johnson-Laird, P. N. (2010). Mental models and human reasoning. *Proceedings of the National Academy of Science 107*(43), 18243-18250.

Justi, R., & Gilbert, J. K. (2002a). Modelling, teachers views on the nature of modelling, and implications for the education of modellers. *International Journal of Science Education 24*(4), 369-387.

Justi, R., & Gilbert, J. K. (2002c). Science teachers' knowledge about and attitudes towards the use of models and modellind in learning science. *International Journal of Science Education 24*(12), 1273-1292.

Justi, R., & Gilbert, J. K. (2003a). Models and modelling in chemical education. In J. K. Gilbert, O. De Jong, R. Justi, D. F. Treagust, & J. H. V. Driel (Eds.), *Chemical education: Towards research-based practice*. Drodrecht. The Netherlands: Kluwer: 47-68.

Justi, R., & Van Driel, J. H. (2005). A case study of the development of a beginning chemistry teacher's knowledge about models and modelling. *Research in Science Education 35*(2), 197-219.

Karpov, V. Y. (2003). Vygostsky's doctorine of scientific concepts:Its role for contemporary education. In A. Kozulin, B. Gindis, V. S. Ageyev, & S. M. Milner (Eds.), *Vygostsky's educational theory in cultural context*. Cambridge, UK: Cambridge university press: 65-82.

Kumekpor, T. K. B (2002). *Research methods and techniques of social research.* Accra: SonLife Press & Services.

Kozulin, A. (2003). Psychological tools and mediated learning. In A. Kuzulin, B. Gindis, V. S. Ageyev, & S. M. Miller (Eds.), *Vygotsky's educational theory in cultural context*. Cambridge, UK: Cambridge university press: 15-38.

Labaree, D. F. (2011). Consuming the public school. *Educational Theory 61*, 381-394.

Lajium, D., Ismail, Z., & Mohd. Yunus, H. (2005). *Form four students' mastery of matter concept.* Penang.

Lay, J. F. (2009). Logical thinking abilities among form 4 students in the interior division of Sabah, Malaysia. *Journal of Science and Mathematics Education in Southeast Asia 32*(2), 161-187.

Lin, J. W., & Chiu, M. H. (2007). Exploring the characteristics and diverse sources of students' mental models of acid and bases. *International Journal of Science Education 29*(6), 771-803.

Lin, J. W., & Chiu, M. H. (2010). The mismatch between students' mental models of acids/bases and their sources and their teachers' anticipations thereof . *International Journal of Science Education 32*(12), 1617-1646.

Lofgren, L., & Hellden, G. (2008). Following young students' understanding of three phenomena in which transformations of matter occur. *International Journal of Science and Mathematics Education 6*(3), 481-504.

Lofgren, L., & Hellden, G. (2009). A longitudinal study showing how students use a molecule concept when explaining everyday situations. *International Journal of Science Education 31*(12), 1631-1655.

Maeyer, J., & Talanquer, V. (2010). The role of intuitive heuristics in students' thinking: Ranking chemical substances. *Science Education 94*(6), 963-984.

Maia, P. F., & Justi, R. (2009). Learning of chemical equilibrium through modelling-based teaching. *International Journal of Science Education 31*(5), 603-630.

Maki, U. (2001). Models: Philosophical aspects. In J. S. Neil, & B. B. Paul (Eds.), *Encyclopedia of the social and behavioural sciences*. Oxford, UK: Pergamon: 9931-9937.

Martin, M. O., Mullis, I. V., & Foy, P. (2008). *TIMSS 2007 international science report: Findings from IEA's trends in international mathematics and science study at the fourth and eighth grades.* Chestnut Hill, MA: The International Study Center, Boston College.

Mason, J. (2002). *Qualitative researching.* London, UK: Sage.

Matthews, M. R. (2007). Models in science and in science education: An introduction. *Science & Education 16*(7/8), 647-652.

McBroom, R. A. (2011). *Pre-service science teachers' mental models regarding dissolution and precipitation reactions.* Raleigh, North Carolina: North Carolina State University.

McCarney, R., Warmer, J., Iliffe, S., Van Haselen, R., Griffin, M., & Fisher, P. (2007). The Hawthorn effect: A randomised controlled trial. *BM Med Res Methodology 7*, 30.

McClary, L., & Talanquer, V. (2011). Heuristic reasoning in chemistry: Making decisions about acid strength . *International Journal of Science Education 33*(10), 1433-1454.

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

Michelle, R. (2004). *Middle school students' intuitive techniques for solving algebraic word problems.* USA: Univesity of Arizona.

Mills, G. E. (2000). *Action research: A guide for the teacher researcher.* Columbus: Prentice Hall.

Moseley, C., Desjean-Perrotta, B., & Utley, J. (2010). The Draw-An-Environment Test Rubric(DAET-R): Exploring pre-service teachers' mental models of the environment. *Environmental Education Research, 16*(2), 189-208.

Mulford, D. R., & Robinson, W. R. (2002). An inventory for Alternate Conceptions among First-Semester General Chemistry students. *Journal of Chemical Education 79*(6), 739-744.

Myers, R. (2009). *The Basics of Chemistry.* Greenwood Publishing Group.

Nersessian, N. J. (2008). Mental modelling in conceptual change. In S. Vosniadou (Ed.), *International handbook of research on conceptual change*. New York, NY: Routledge: 391-416.

Nobes, G., Moore, D. G., Clifford, B. R., Butterworth, G., Panagiotaki, G., & Siegal, M. (2003). Children's understanding of the earth in a multicultural community: Mental models or fragments of knowledge? *Developmental Science 6*(1), 72-85.

Nolen, S. B. (2003). Learning environment, motivation, and achievement in high school science. *Journal of Research in Science Teaching 40*, 347-368.

Oh, P. S., & Oh, S. J. (2011). What teachers of science need to know about models. An overview. *International Journal of Science Education 33*(8), 1109-1130.

Osborne, J., Simon, S., & Collins, S. (2011). Attitude towards science. A review of the literature and its implications . *Journal of Research in Science Teaching 25*, 1049-1079.

Paik, S., Choo, B. K., & Go, Y. M. (2007). Korean 4-to 11-year-old student misconceptions of heat and temperature. *Journal of Research in Science Teaching 44*(2), 284-302.

Palmer, B. (2006). Children's alternate conceptions of physical and chemical change obtained from historical sources compared with those found in other recent studies. *Australian Journal of Education in Chemistry, 66*, 12-17.

Panagiotaki, G. N., & Potton, A. (2009). Mental models and other misconceptions in children's understanding of the earth. *Journal of Experimental Child Psychology 104*(1), 52-67.

Papageorgiou, G., Grammaticopoulou, M., & Johnson, P. M. (2010). Should we teach primary pupils about chemical change? *International Journal of Science Education 32(*12), 1647-1664.

Park, E. J., & Light, G. (2009). Identifying atomic structure as a threshold concept: Student mental models and troublesomeness. *International Journal of Science Education 31*(2) , 233-258.

Parson, R. D., & Brown, K. S. (2002). *Teachers as a reflective practitioner and action researcher.* Belmont, Calif: Wadsworth/Thomson learning.

Patton, M. Q. (2002). *Qualitative research and evaluation methods (3rd ed.).* Thousand Oaks, CA: Sage.

Portides, D. (2008). Models. In S. Psillos, & M. Curd (Eds.), *The routledge companion to philosophy of science*. New York, NY: Routledge: 385-395.

Prawat, R. S. (2008). Constructivism. In N. J. Salkind (Ed.), *Encylopedia of educational psychology*. Los Angeles, CA: Sage: 182-183.

Prenhall. (2005). *Writing and balancing chemical equations.* Pearson Prentice Hall, Inc.

Punch, K. F. (2006). *Developing effective research proposals (2nd ed.).* London: Sage Publications Ltd.

Rapp, D. N. (2005). Mental models: Theoretical issues for visualisations in science education. In J. K. Gilbert (Ed.), *Visualisation in science education*. Dordrecht. The Netherlands: Springer: 43-60.

Robson, C. (2002). *Real world research (2nd ed.).* Singapore: Best-Set Typesetter Ltd, Hong Kong.

Rogoff, B. (2006). Conveiving the relationship of the social world and the individual. In J. Gilbert (Ed.), *Science education: Major themes in education*. London, England: Routledge: 38-60.

Schmidt H, J. (2000). In the maze of chemical nomenclature-how students name oxo salts. *International Journal of Science Education 22*(3), 253-264.

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Acher, A., Fortus, D., et al. (2009). Developing a learning progression for scientific modelling: Making scientific modelling accessible and meaningful for learners. *Journal of Research in Science Teaching 46*(6), 632-654.

Scott, D., & Usher, R. (2011). *Reasearching education data, methods and theory in educational enquiry.* London, UK: Continuum.

Seidu, A. (2007). *Modern approaches to research in educational administration: Revised Edition.* Kumasi: Payless Publication Limited.

Shepardson, D. P., Wee, B., Priddy, M., & Harbor, J. (2007). Students' mental models of the environment. *Journal of Research in Science Teaching 44*(2), 327-348.

Shusaku, H., & Bret, U. (2009). Making connections to the 'real world': A model building lesson. *Physics Education 44*(6), 633-638.

Sileshi, Y. (2011). *Chemical Reaction: Diagnosis and Towards Remedy of Misconceptions.* Addis Ababa, Ethiopia: Kotebe College of Teacher Education.

Silva, C. (2007). The role of models and analogies in the electromagnetic theory: A historical case study. *Science & Education 16*(7/8), 835-848.

Simon, M. K., & Goes, J. (2013). *Dissertation and scholarly research: Recipes for success.* Seattle, WA: Dissertation Success LLC.

Sozbilir, M. (2003). What students' understand from entropy? A review of selected literature. *Journal of Baltic Science Education 3*(3), 21-27.

Sozbilir, M., & Bennett, J. M. (2007). A study of Turkish chemistry undergraduates' understanding of entropy. *Journal of Chemical Education 84*(7), 1204-1208.

Sozbilir, M., Pinarbasi, T., & Canpolat, N. (2010). Prospective chemistry teachers' conceptions of chemical thermodynamics and kinetics. *Eurasia Journal of Mathematics, Science & Technology Education 6*(2), 111-121.

Steeples, C. (2004). *Using action-oriented or participatory research methods for research on networked learning, Networked Learning Conference, NCL Proceedings, Symposium 4*. Retrieved July 20, 2016, from http://www.nlc2004/proceedings/symposia/symposium4/steeples.htm

Stein, M., Larrabee, T., & Barman, C. (2008). A study of common beliefs and misconceptions in physical science. *Journal of Elementary Science Education 20*(2), 1-11.

Straatemeier, M., Van der Maas, H. L., & Jansen, B. R. (2008). Children's knowledge of the earth: A new methodological and statistical approach. *Journal of Experimental Child Psychology 100*(4), 276-296.

Suckling, C. J., Suckling, K. E., & Suckling, C. W. (1978). *Chemistry through models: Concepts and application of modelling in chemical science, technology and industry*. London, UK: Cambridge University Press.

Taber, K. S. (2000). *What should we tell the pupils about why reactions happen*. Retrieved July 20, 2016, from http://www.leeds.ac.uk/educol/documents/00001652.htm

Taber, K. S. (2003). Mediating mental models of metals: Acknowledging the priority of the learner's prior learning. *Science Education 87*(5), 732-758.

Taber, K. S. (2006). Beyond constructivism: The progressive research programme into learning science. *Studies in science education,42*(1), 125-184.

Taber, K. S. (2008). Towards a curricular model of the nature of science. *Science & Education*, *17*(2), 179-218.

Taber, K. S. (2009). College students' conceptions of chemical stability: The widespread adoption of a heuristic rule out of context and beyond its range of application. *International Journal of Science Education*, *31*(10), 1333-1358.

Taber, K. S., & Garcia-Franco, A. (2010). Learning processes in chemistry: Drawing upon cognitive resources to learn about the particulate structure of matter. *Journal of the Learning Sciences 19*(1), 99-142.

Talanquer, V. (2002). Minimizing misconceptions. *The Science Teacher*, *69*(8), 46-49.

Talanquer, V. (2006). Commonsense chemistry: A model for understanding students' alternative conceptions. *Journal of Chemical Education 83*(5), 811.

Talanquer, V. (2010). Exploring dorminant types of explanations built by general chemistry students. *International Journal of Science Education 32*(18), 2393-2412.

Teichert, M. A., & Stacy, A. M. (2002). Promoting understanding of chemical bonding and spontanneity through student explanation and integration of ideas. *Journal of Research in Science Teaching 39*(6), 464-496.

Treagust, D. F., Chittleborough, G. D., & Mamiala, T. L. (2004). Students' understanding of the descriptive and predictive nature of teaching models in organic chemistry. *Research in Science Education 34*(1), 1-20.

Tregidgo, D., & Ratcliffe, M. (2000). The use of modelling for improving pupils' learning about cells. *School Science Review 81*, 53-59.

Tytler, R. (2000). A comparison of year 1 and year 6 students' conceptions of evaporation and condensation: Dimensions of conceptual progression. *International Journal of Science Education 22*(5), 447-467.

Upadhyay, S. K. (2006). *Chemical kinetics and reaction dynamics.* New York, NY: Springer.

Van der Veer, R. (2007). Vygotsky in context. In H. Daniels, M. Cole, & J. V. Wertssch (Eds.), *The cambridge companion to Vygotsky*. Cambridge, UK: Cambridge university press: 21-49.

Van Driel, J. H., & Verloop, N. (2002). Experienced teachers' knowledge of teaching and learning of models and modelling in science education. *International Journal of Science Education 24*(12), 1255-1272.

Viennot, L. (2001). *Reasoning in physics: The part of common sense.* Dordrecht, The Netherlands: Kluwer Academic.

Viraf, J. D. (2008). *Simplified ICSE chemistry*. Retrieved July 25, 2016, from http//www.goodreads.com/author/show/14170482.viraf-J-Dalal

Vosniadou, S. (2012). Reframing the classical approach to conceptual change: Preconceptions, misconceptions and synthetic models. In B. J. Fraser, K. Tobin, & C. J. McRobbie (Eds.), *Second international handbook of science education*. Dordrecht, The Netherlands: Springer: 119-130.

Vosniadou, S., Skopeliti, I., & Ikospentaki, K. (2005). Reconsidering the role of artifactsin reasoning: Children understanding of the globe as a model of the earth. *Learning and Instruction 15*(4), 333-351.

Vosniadou, S., & Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology*, *24*(4), 535-585.

Wallace, C. S., Hand, B., & Prain, V. (2004). Introduction: Does Writing Promote Learning in Science. In C. S. Wallace, B. Hand, & V. Prain (Eds.), *Writing and learning in the science classroom*. Dordrecht, Boston: Kluwer Academic Publishers: 3.

Wiling, C. (2008). *Introducing qualitative research in psychology: Adventures in theory and method.* Berkshire, UK: Open University Press.

Wright, M. R. (2004). *An introduction to chemical kinetics.* Chichester, UK: John Wiley & Sons.

Yalcinkaya, E., Tastan, O., & Boz, Y. (2009). High school students' conceptions about energy in chemical reactions. *Pamukkale University Journal of Education 26*, 1-11.

Yin, R. K. (2003). *Case study research: Design and methods.* Thousand Oaks, CA: Sage.

Zohrabi, M. (2013). Mixed method researcher: instruments, validity, reliability and reporting findings. *Theory and Practice in Language Studies 3*(2), 254-262.

Zumdahl, S. S. (2005). *Chemical principles.* Boston, MA: Houghton Mifflin.

Zumdahl, S. S., & Zumdahl, S. L. (2010). *Chemistry.* Belmont, CA: Brooks Cole.

Zumdahl, S., Zumdahl, S. L., & DeCoste, D. J. (2007). *World of chemistry.* Evanston, IL: Houghton Mifflin.