UNIVERSITY OF CAPE COAST

STUDENTS’ CONCEPTUAL DIFFICULTIES IN THERMOCHEMISTRY

GEORGE OFORI-AHENKAN

2022

UNIVERSITY OF CAPE COAST

STUDENTS’ CONCEPTUAL DIFFICULTIES IN THERMOCHEMISTRY

BY

GEORGE OFORI-AHENKAN

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

AUGUST 2022

DECLARATION

Candidate's Declaration

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

Candidate's Signature: …………………………… Date: …………………..

Name: George Ofori-Ahenkan

Supervisor's Declaration

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

Supervisor's Signature: …………………………… Date: ………………...

Name: Dr. Kenneth Adu-Gyamfi

ABSTRACT

This study investigated conceptions of senior high school students in thermochemistry. This led to the exploration of students' alternative conceptions in thermochemistry and the factors that contribute to those alternative conceptions. A convergent parallel mixed methods research design was employed in the study to collect quantitative and qualitative data. The design used three stages, which included collection of quantitative and qualitative data, analysis of data and merging of results, and interpretation of data on conceptions in thermochemistry and prerequisite concepts. Through a multistage sampling procedure, 141 students responded to two tests, one on thermochemistry and the other on prerequisite concepts to thermochemistry. Also, 12 out of the 141 students were purposively sampled for interviews. Quantitative data were analysed using frequencies and percentages, bar charts, and Pearson product-moment correlation statistic, whereas qualitative data were analysed thematically. The results showed that students had alternative conceptions and other conceptual difficulties in thermochemistry in the form of factual misconceptions, conceptual misunderstandings, preconceived notions, and vernacular misconceptions, and the factors accounting for these alternative conceptions were teacher-related, textbook-related, and daily experiences. Though weak, a positive correlation existed between students' achievements in the prerequisite concepts and thermochemistry. It is, therefore, recommended among others that chemistry teachers in the SHS should build their capacity on identification and correction of students' alternative conceptions in thermochemistry.

KEY WORDS

Alternative conceptions

Chemistry

Conceptual difficulties

Prerequisite concepts

Students

Thermochemistry

ACKNOWLEDGEMENTS

I would like to express my profound appreciation to my supervisor, Dr. Kenneth Adu-Gyamfi, in the Department of Science Education, for his guidance, assistance, and swiftness with which he guided this research. Had it not been his professional and insightful comments, suggestions, corrections, and encouragement, this work would not have been successful. I am very much appreciative.

More so, I would like to thank my family, especially, my father, Odeneho Shie Boffour II (Paramount Chief of Brodi Traditional Area) known in his private life as Kenneth Okrah, my uncle, Emmanuel Mensah, my mothers, Ernestina Mansa and Victoria Diawuo, my siblings, Reagan Opoku, Dorcas Foriyana, Jonas Nii Odamten, Regina Kontor, Esther Asabea, and Grant Abayie Mensah. It is their undaunted support that has seen me this far.

My sincere gratitude again goes to Dr. (Mrs.) Christiana Asiedu in the Department of Adult Health Nursing, University of Cape Coast, for her unflinching support in diverse ways throughout my studies. Again, to the Heads of Schools, Heads of Science Departments, Chemistry Teachers and Students of the schools in the Cape Coast Metropolis who granted me the opportunity to conduct the study in their schools, I am very grateful. I am also grateful to all my colleagues, especially, Rev. Bro. Nicholas Arthur, Mr. Francis Boahen, and Mr. Samuel Agbene for their advice and contributions to completing this study. Finally, my appreciation goes to Mr. Ishmael Fynn, Mr. Richard Mantey-Williams and all my colleague teachers in Prestea Senior High/Technical School for their encouragement.

DEDICATION

To my father, Odeneho Shie Boffour II (Brodihene)

TABLE OF CONTENTS

	Page
DECLARATION	ii
ABSTRACT	iii
KEY WORDS	iv
ACKNOWLEDGEMENTS	v
DEDICATION	vi
LIST OF TABLES	x
LIST OF FIGURES	xi

CHAPTER ONE: INTRODUCTION

Background to the Study	1
Statement of the Problem	6
Purpose of the Study	9
Research Questions	9
Significance of the Study	10
Delimitation	11
Limitations	12
Definition of Terms	12
Organisation of the Study	13

CHAPTER TWO: LITERATURE REVIEW

Alternative Conceptions and Conceptual Difficulties in Thermochemistry	15
Factors Accounting for Students’ Alternative Conceptions	26
Relations of Prerequisite Concepts to Thermochemistry	39
Conceptual Framework	43
Summary of Reviewed Literature	48

CHAPTER THREE: RESEARCH METHODS

Research Design 50

Study Area 53

Population 54

Sampling Procedure 55

Data Collection Instruments 57

Data Collection Procedures 61

Data Processing and Analysis 63

CHAPTER FOUR: RESULTS AND DISCUSSION

Categories of Students' Alternative Conceptions and other Conceptual Difficulties in Thermochemistry 67

Factors Accounting for Students' Alternative Conceptions 102

Relationship between Students Achievement in Prerequisite Concepts and Achievement in Thermochemistry 117

CHAPTER FIVE: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary 142

Key findings 143

Conclusions 144

Recommendations 146

Suggestions for Further Research 147

REFERENCES 149

APPENDIX A: Test ON Prerequisite Concepts (TPRC) 165

APPENDIX B: Two-tier Diagnostic Test on Thermochemistry (TTDTT) 172

APPENDIX C: Interview On Factors on Alternative Conceptions in Thermochemistry (IFACT) 180

LIST OF TABLES

Table Page

1 Background Characteristics of Respondents (N = 141) 56

2 Students' Understanding of Thermochemistry Concept (N = 141) 68

3 Students' Understanding of the Prerequisite Concepts (N = 141) 118

4 Pearson Product-moment Correlation between Scores in Prerequisite Concepts and Thermochemistry 139

LIST OF FIGURES

Figure		Page
1	Conceptual framework of the study	48
2	Diagrammatic representation of the convergent parallel mixed-methods design adapted from Creswell (2012).	51
3	Bar chart of categories of students’ alternative conceptions in thermochemistry.	92
4	Bar chart of categories of students’ alternative conceptions in prerequisite concepts.	134
5	Scatter plot of Pearson product-moment correlation between scores in prerequisite concepts and thermochemistry scores.	138

CHAPTER ONE

INTRODUCTION

The study of energy is considered as an important concept for science, technology, and engineering students as well as the general scientific community (Cooper & Klymkowsky, 2013). In the context of chemistry (chemical education), energy is considered under the broader concept of thermochemistry. Thermochemistry has many crucial applications such as the burning of fuels and the generation of electricity from power plants (Dukhan, 2016). Students usually have concepts in mind that precede and may contradict the concepts they learn from formal instructions on a variety of topics (Wren & Barbera, 2014), of which thermochemistry is inclusive. These concepts that the students hold aside the right concepts accepted by scientists are regarded as the students' alternative conceptions (Adu-Gyamfi & Ampiah, 2019). These students' alternative conceptions may lead to conceptual difficulties which antagonise their understanding of the right concepts. This current study seeks to find the conceptions students have in thermochemistry and their causes.

Background to the Study

Within the Ghanaian educational system, energy is considered as a key concept which is being taught right from the lower levels of education (basic school) to institutions of higher learning. Energy is an interdisciplinary concept (Dreyfus et al., 2014) which is related to comprehending the manner in which chemical systems exist (interactions of atoms and molecules) as well as in biological systems (Becker & Cooper, 2014). The concept of energy cuts across the three major branches of natural science; biology, chemistry, and physics. Energy in biology is concerned with energy transformations at the molecular level and its relations with organisms and ecosystem levels. In physics, energy is treated by predominantly concentrating on mechanical energy with lesser attention given to other forms of energy (Dreyfus et al., 2014).

In chemistry, energy is studied under the concept of thermodynamics. Thermodynamics deals with the relationships between heat and other forms of energy as well as the changes in the forms of energy (Ayyildiz & Tarhan, 2012; Ebbing & Gammon, 2009). Students in most of engineering programmes as well as chemistry and physics courses study thermodynamics but with some variations from one field to another. Knowledge and principles of thermodynamics is applied in heating, cooling, and air-conditioning. Also, thermodynamics is applied in chemical reactions such as burning fossil fuels, generation of steam in steam power plants, and nuclear reactions in nuclear power plants (Dukhan, 2016). Specifically, in the field of chemistry, the concept of energy is taught as thermochemistry, which is one of the areas of thermodynamics (Ebbing & Gammon, 2009). Thermochemistry is the study of heat change in chemical reactions (Chang, 2010).

Thermochemistry, at the senior high school level in Ghana, contains sub-concepts such as system and surroundings, energy and enthalpy, endothermic and exothermic reactions, standard states and standard enthalpy change of reactions, Hess's law of heat summation, Born-Haber cycle, enthalpy of neutralisation of acid-base reactions and bonds energy (thermochemical equations) (Ministry of Education [MoE], 2010). Within the thermochemistry concept, students are required to describe the energy accompanied by chemical reactions as either endothermic or exothermic and quantifying the amount of energy associated with the occurrences of such chemical reactions. This explicitly indicates that emphasis is laid on heat energy in the study of thermochemistry. However, students, over the years, have had difficulties in differentiating heat from temperature (Ayyildiz & Tarhan, 2012).

Chen, Zhang, Guo, and Xin (2017) establish a relationship among the various sub-concepts as exothermic and endothermic reactions are fundamental sub-concepts that are necessary to be understood before attempting to understand all the other sub-concepts in thermochemistry. Gaining an understanding of the causes of heat quantity change both at the micro and macro levels, as well as understanding chemical bonds and reaction heat and enthalpy, requires that exothermic and endothermic reactions are first mastered by the student. Only after grasping the sub-concept of reaction heat and enthalpy, can the student gain a conceptual understanding of the thermochemical equations sub-concept. Chen et al. further add that mastery of the thermochemical equations sub-concept is a prerequisite to the comprehension of the Hess’s law of heat summation and Born-Haber cycles.

According to Ayyildiz and Tarhan (2012), some relevant previous knowledge in concepts, such as particulate nature of matter, atom, element, compound, molecule, physical and chemical changes, and chemical bonds, is necessary in the achievement of better understanding of the thermochemistry concept. Becker and Cooper (2014) are of the view that, students must elaborate on their comprehension of atomic-molecular structure while creating a linkage with their comprehension of charges in species, which will then increase their intellect in energy changes in more complex atomic-molecular systems. Becker and Cooper further cite examples that recognising the fact that haphazard rise and fall in electron density leads to the formation of temporary dipoles that subsequently give rise to induced dipole interactions in neighbouring species is very necessary to understanding energy changes that go along with interactions between neutral atoms such as helium. Also, knowledge about the valence shell electron pair repulsion (VSEPR) theory and electronegativity are prerequisite to understanding the energy changes that occur in interactions between species such as water and ethanol.

Students must, therefore, be exposed to some crucial and necessary concepts that are a prerequisite to the learning of thermochemistry (Ayyildiz & Tarhan, 2012; Becker & Cooper, 2014). When the crucial prerequisite concepts are not well understood by the students, their pre-existing conceptions will continue to exist. The continuous existence of the students' pre-existing conceptions will lead to difficulty in grasping the thermochemistry concept. This will then have a negative effect on how students answer questions on thermochemistry as well as applying knowledge in phenomena that are related to the concept (Pan, Li, Li, & Tang, 2017).

Hanson, Taale, and Antwi (2011) assert that even though chemistry is an interlinkage among other scientific disciplines, educators, researchers, and teachers have concluded that chemistry is a difficult subject for students due to its abstract nature. Uzezi, Ezekiel, and Auwal (2017) report that students are alleging that thermochemistry is among chemical concepts that are difficult in chemistry. Bain, Moon, Mack, and Towns (2014) articulate that many evidential reports from research have reiterated students' difficulties in understanding the thermochemistry concept. Reasons for which most chemistry concepts, including thermochemistry, seem difficult for some students is in how abstract and symbolic the concepts are. Saricayir, Ay, Comek, Cansiz, and Uce (2016) reiterate that the leading challenge facing students in understanding the thermochemistry concept is in how theoretical the concept is; and curriculum overload, lack of concentration during lessons, and lack of motivation on the part of students (Sokrat, Tamani, Moutaabbid, & Radid, 2014). The conceptions possessed by students prior to learning thermochemistry can also have effects on their understanding of the concept (Pan et al., 2017).

Carson and Watson (2002) claim that detailed reports from some research indicate that students have some alternative conceptions in thermochemistry. For example, students explain entropy as disorder, which is mostly interpreted to mean chaos, randomness or instability in a chemical system. Most students think of temperature as a measure of the amount of energy contained in an object (Dukhan, 2016). Temperature is synonymous to heat, energy is released when bonds are broken and energy is absorbed when bonds are formed (Cooper & Klymkowsky, 2013) are some of students' alternative conceptions.

Students inappropriately explain that a burning candle is an endothermic process since heat is required to kick-start the reaction as opposed to the correct explanation that despite the requirement of heat to initiate the reaction, once the burning starts, the reaction continues without any further intake of energy but energy is rather given off in the form of light and heat. Again, students maintain the ideas that energy is created and used up in chemical reactions, which contradicts the scientific point of view that energy is stored or released in the form of chemical bonds between atoms (Mondal & Chakraborty, 2013). Students are unable to make use of the relation between Q, W, and ΔE (first law of thermodynamics), cannot interpret standard diagrammatic representations, and do not recognise the fact that a change in G of a system is directly related to change in S of the universe (Woldamanuel, 2015). Hence, there was the need to find out the conceptions SHS chemistry students had in learning thermochemistry.

Statement of the Problem

Research has revealed that the lack of accurate understanding of essential chemistry concepts and most of the scientifically inaccurate concepts that the students possess are carried from early years of schooling to institutions of higher learning (Woldamanuel et al., 2015). These inaccurate concepts possessed by students are their alternative conceptions. These alternative conceptions need to be corrected as quickly as possible. Nonetheless, since alternative conceptions are people's personal views that do not conform to the scientifically accepted views, the owners of such alternative conceptions must make efforts to correct them (Gooding & Metz, 2011). Prior to the students correcting their alternative conceptions about thermochemical concepts, it is the duty of educators and researchers to diagnose and detect such alternative conceptions to assist in finding solutions to them (Adu-Gyamfi & Ampiah, 2019).

In a study conducted by Saricayir et al. (2016), majority of students possessed the idea that any substance that has higher temperature will subsequently have a higher heat, a mixture of substances will have an increase in heat if the total final temperatures of the constituent substances is greater than their total initial temperatures, and heat is transferred from a body with bigger mass to a body with smaller mass. These ideas of students are contrary to the correct scientific explanations that the magnitude of heat contained in a substance is dependent on the temperature difference between the body and its surroundings but not the temperature of the substance alone. The heat of a mixture of substances will only increase if the magnitudes of the differences between the initial temperatures and final temperatures of the constituent substances vary significantly, and the direction of heat flow is from a body with higher temperature to a body with lower temperature respectively (Ebbing & Gammon, 2009). Many students inaccurately express heat as a physical function of ‘hot’ or ‘cold’ (Lee, 2014). Furthermore, students have the conception that enthalpy, entropy, internal energy, and activation energy are forms of energy; and internal energy and enthalpy are the same (Bain et al., 2014).

In the Ghanaian context, the West African Examination Council (WAEC) Chief Examiner’s report reveals that most students fail to give correct meaning to a hypothetical equation that depicts an exothermic reaction (WAEC, 2011). Students cannot correctly draw energy profile diagram for an endothermic reaction; students define heat of neutralisation reaction as heat change involved in the reaction between one mole of acid and one mole of base instead of one mole of H^+ from an acid and one mole of OH^- from a base; the term dissociation is mistaken for atomisation; and students define a closed system by mentioning only of heat/energy without making mentioning of matter in the definition (WAEC, 2013). Moreover, students cannot assign reasons to the differences in the energy changes accompanied with neutralisation reactions between a strong acid and a strong base, and between a weak acid and a strong base (WAEC, 2018).

Some studies have been conducted on students' alternative conceptions and conceptual difficulties on diverse concepts in chemistry both in and outside of Ghana (Adu-Gyamfi & Ampiah, 2019; Adu-Gyamfi et al., 2015; Bain et al., 2014; Dukhan, 2016; Hanson et al., 2011; Saricayir et al., 2016; Sokrat et al., 2014; Woldamanuel et al., 2015). However, researching into students' conceptual difficulties in thermochemistry in the Ghanaian context needs attention as it appears to be unexplored amid all the problems outlined in this study. For instance, Hanson et al. (2011) investigated Ghanaian students' conceptions on properties of matter, elements, compounds, mixtures, physical change, chemical change and the acid-base concept, but not in thermochemistry. Adu-Gyamfi et al. (2015) researched into students' alternative conceptions about the use of H_2O, OH^-, and H^+ in balancing redox reactions. More so, Adu-Gyamfi and Ampiah (2019) investigated and categorised students' alternative conceptions in the application of redox reactions in everyday life, but the causes of the alternative conceptions were not investigated. Woldamanuel et al. (2015) investigated students' conceptual difficulties in thermodynamics in an Ethiopian University but did not make attempts of categorising the conceptual difficulties and investigating the sources of the difficulties. Moreover, it appeared from the search in literature that no study had used statistical means to establish a correlation between the prerequisite concepts and thermochemistry, despite literature claiming that knowledge from the prerequisite concepts is needed for learning thermochemistry. Therefore, there was the need for investigating the conceptions of Ghanaian students in thermochemistry in order to identify and to probe the causes of possible alternative conceptions and conceptual difficulties. Also, there was the need to probe the magnitude of the relationship between the prerequisite concepts and thermochemistry.

Purpose of the Study

The purpose of this study was to investigate the conceptions SHS chemistry students have in thermochemistry. The investigation then helped in diagnosing the causes of the students' alternative conceptions in thermochemistry. Specifically, the study targeted the following objectives, to:

1. explore students' alternative conceptions and other conceptual difficulties in thermochemistry,
2. explore the factors that account for students' alternative conceptions in thermochemistry, and
3. examine the relationship between students' achievement in prerequisite concepts and their achievement in thermochemistry.

Research Questions

The following research questions were used:

1. What are the categories of students' alternative conceptions and other conceptual difficulties in thermochemistry?
2. What are the factors that account for students' alternative conceptions in thermochemistry?
3. How is students' achievement in prerequisite concepts related to their achievement in thermochemistry?

Significance of the Study

The findings on categories of students' alternative conceptions and other conceptual difficulties in thermochemistry would provide chemistry educators and researchers with empirical (both quantitative and qualitative) basis for further research in this all-important area in chemistry. The categories of alternative conceptions present in learning thermochemistry would contribute to the debate on which categories of alternative conceptions are present in learning chemistry at the high school level. Chemistry educators and researchers could come out with cognitive conflicting instructional approaches to help students overcome their alternative conceptions and other conceptual difficulties in learning thermochemistry.

The findings on factors contributing to students' alternative conceptions and other conceptual difficulties would help the Ministry of Education through the Ghana Education Service (GES) to support the schools in creating environment conducive for learning thermochemistry. The findings would further help chemistry educators and researchers to appreciate the factors that contribute to the alternative conceptions of students in thermochemistry. Curriculum planners, such as National Council for Curriculum and Assessment (NaCCA) could recommend participatory teaching and learning approaches noted for helping to eliminate alternative conceptions for teaching chemistry at the SHS level.

The findings on the relationship that exists between prerequisite concepts (such as particulate nature of matter, structure of the atom, periodicity, and chemical bonding) and thermochemistry would help chemistry educators to appreciate the need to teach the prerequisite concepts to the understanding of students. Chemistry educators and researchers could further conduct research into teachers' conceptions and instructional strategies on the prerequisite courses.

Delimitation

Amid the problems students have in answering questions on thermochemistry as enumerated by the WAEC Chief Examiner's report and other literature sources, there could have been a plan of exploring an effective teaching model to teach thermochemistry. However, this study only focused on investigating the conceptions SHS students have in thermochemistry and the causes of such conceptions. This was because it is the opinion of the researcher that students' problems in thermochemistry would be persistent should their alternative conceptions continue to exist despite recommending a particular teaching model to teach thermochemistry.

There were a number of concepts under thermochemistry, however, test items on thermochemistry were sampled from energy and enthalpy, endothermic and exothermic processes, energy in food and fuels, standard state and standard enthalpy change of reactions, enthalpy of neutralisation of an acid-base reaction, Hess's law of heat summation and the Born-Haber cycle, and bonds energy. Laws of thermodynamics, and heat capacity and specific heat capacity were excluded as they were calculation intensive and would take students longer time in calculating and applying the appropriate concepts. Justification for such calculations was also tedious and would require enough time and writing space to do so.

A survey technique was used as a mean of gathering quantitative data for this study due to its efficiency in collecting data from a larger sample within a relatively shorter time. Although data from secondary sources could help to identify some causes of students' alternative conceptions, the data collected in this study were solely primary data because the factors causing students' alternative conceptions can vary from one place to another.

Limitations

The reliability of the data collection instruments might, to some extent, influence the quality of data and subsequently, the research findings. The use of the Pearson product-moment correlation could only reveal association between the prerequisite concepts and thermochemistry, but could not be used to determine causality. Data gathered through the use of interview approaches were mostly subjective in nature and the transcription and analysis of interview data relied greatly on the discretion of the researcher. Hence, there could be a possibility of some researcher biases, which might not reflect the precise opinions expressed by students.

Definition of Terms

Alternative conceptions in this study refer to students' ideas or concepts that contradict the scientific facts accepted by mainstream scientists.

Conceptual change refers to the process of streamlining one's prevailing conceptions, usually alternative conceptions, and developing the acceptable scientific concepts by obtaining new knowledge.

Conceptual difficulties as used in this study are the difficulties students have in understanding of concepts. They occur when students try to explain new information from their existing conceptual framework, which ends up to be untrue or unrelated to the scientific concept.

Prerequisite concepts as used in this study are the concepts that students need to understand before they can understand the thermochemistry concept. These concepts are particulate nature of matter, periodicity, physical and chemical changes, and chemical bonding.

Preconceived notions are students' ideas obtained from their daily experiences.

Nonscientific beliefs are students' conceptions that are established on the traditions of religion and myths.

Conceptual misunderstanding is the inability of students' knowledge obtained from science lessons in helping them to alienate their earlier preconceived notions and nonscientific beliefs.

Vernacular misconceptions are the literal or inaccurate meanings that students give to scientific words in their daily activities.

Factual misconceptions, as appearing in this study, are the persisting students' conceptions built on false ideas that were learnt from their early ages of life and have not been confronted till their present stage of learning thermochemistry.

Organisation of the Study

The study was organised into five chapters. The first chapter (Introduction) and other four chapters, organised to explain issues leading to answering the research questions.

The second chapter (Literature Review) focused on the review of literature that were connected to this current study. Subsections in the Literature Review were categories of students' alternative conceptions and other conceptual difficulties, factors accounting for students' alternative conceptions, relations of prerequisite concepts to thermochemistry, and conceptual framework of the study.

Research Methods, the third chapter, was concerned with how the research was conducted. Specific sections under this chapter were the research design, study area, population, sampling procedure, data collection instruments, data collection procedures, and data processing and analysis.

The fourth chapter (Results and Discussion) was concerned with presentation of results and evaluating the findings of this current study and exploring the inferences of the findings to practical applications. The results and the findings were presented in line with the research questions.

The fifth chapter (Summary, Conclusions, and Recommendations) presented a summary of the whole study and made logical deductions of the findings as well as gave recommendations based on the findings.

CHAPTER TWO

LITERATURE REVIEW

The focus of this study was to investigate the conceptions that SHS chemistry students have in thermochemistry and to diagnose the causes of the students' alternative conceptions. This chapter is concerned with the examination of existing literature that have relations to this study, and whose implications are crucial for the development of this study. Specifically, literature is reviewed on alternative conceptions and conceptual difficulties in thermochemistry, factors accounting for students' alternative conceptions, relations of prerequisite concepts to thermochemistry, and the conceptual framework underpinning this study.

Alternative Conceptions and Conceptual Difficulties in Thermochemistry

Most often, students place confidence in some vague ideas (conceptions) that are contrary to concepts expected of them to learn. The possession of such vague ideas can be found among varying groups of students, which include basic education pupils, students of second cycle institutions, undergraduate students, prospective teachers, and graduate students (Taber, 2019). Taber further asserts that aside spanning across varying student groups, students' vague ideas can also vary across a range of topics and different national contexts. Students' perspectives of how they think about all facets of their learning experiences and the world around them, and their conjectures of situations is what is regarded as conception (Adu-Gyamfi & Ampiah, 2019). Students' conceptions of the thermochemistry concept are, therefore, their personal views and understanding of the theories in thermochemistry. These students' personal views and understanding of concepts which are not in conformity to scholarly scientific views are termed as alternative conceptions (Taber, 2019). In other terms, alternative conceptions can be viewed as the interferences to logical system of students and the justifications they give to concepts, based on their past experiences (Faizal, Helmi, Azilawaty, Nurulamirah, & Nurshuhada, n.d.). Students' alternative conceptions exist on almost every science-related topic (Taber, 2019).

The recognition of students' alternative conceptions gained a widespread discussion in the late 1970s through the 1980s. Researchers then began to explore the alternative conception phenomenon by conducting major research to uncover its nature (Taber, 2019). Its inception was influenced by the work of Piadjet (cognitive development theory) who uncovered many alternative notions about the natural world among children, which later shifted from a restriction to the cognitive development theory to conceptions relating to disciplinary content (Taber, 2009). It became an argument, after the dominance of students' alternative conceptions was first reported, that the notions of learners served as an obstruction to effective teaching and therefore needed a careful study (Osborne & Freyberg as cited in Taber, 2009). It is to this effect that Chung (2011) advocates for the use of a diagnostic assessment tool by teachers to determine the readiness of their students before presenting instructions to them. In detecting students' alternative conceptions, qualitative observations, and instruments such as interview, open reasoning, and multiple-choice test items can be used (Aljunid, Mohd, Rashidi, Soh, & Ku Azir, 2018; Schultz et al., 2017).

Parents, folklore, teachers, multimedia, and learners themselves are accountable for the harbouring of alternative conceptions among students (Gooding & Metz, 2011). Students make use of their mental models to explain, describe, assign reasons, and make predictions about a phenomenon based on the knowledge they have (Wiji & Mulyani, 2018). The nonfigurative ideas or thoughts that are developed on common properties of objects or events are what lead to the formation of concepts (Hanson, Twumasi, Aryeetey, Sam, & Adukpo, 2016). For a student to be regarded as having a conceptual knowledge that is correct, such conceptual knowledge must follow the line of contemporary scientific justifications (Aboagye, Amponsah, & Graham, 2019). This, therefore, suggests that the accuracy of the conceptual knowledge obtained is very critical than just the formation of any concept at all which may be inaccurate.

Despite the hard work done by teachers and students in teaching and learning chemistry-related concepts, students often continue to form their own versions of reality (Gooding & Metz, 2011). Again, students often encounter difficulties in learning because the conceptions they possess are not consistent with scientifically accepted concepts (Yang, Noh, Scharmann, & Kang, 2014), which leads to the lack of conceptual understanding of the scientific concepts (Cetin-Dindar & Geban, 2017). The teaching and learning process, therefore, becomes complicated whenever alternative conceptions are formed (Artdej, Ratanaroutai, Coll, & Thongpanchang, 2010). The thermochemistry concept proves to be difficult for most students mainly because it requires analytical, critical, logical, and creative thinking from the students (Retno, Saputro, & Ulfa, 2018). Furthermore, Retno et al. add that numerous abstract concepts of thermochemistry make it extremely problematic and often cause alternative conceptions among students. When alternative conceptions exist among students, they may be able to give correct answers to scientific questions, but may find it very challenging to comprehensively explain such answers (Cetin-Dindar & Geban, 2017). For the purpose of this study, students' alternative conceptions are the conceptual challenges students may have in explaining concepts in thermochemistry, which contradict those accepted by mainstream scientists (Adu-Gyamfi, Ampiah, & Agyei, 2015).

Numerous terms have evolved to describe students' personal views of learning in all fields, which are used as replacing terms for students' alternative conceptions. Preconceptions, children's science, intuitive beliefs, misconceptions, alternative frameworks, students' errors, naive concepts, and alternative views are some of these terms used as substitutes for alternative conceptions (Garnett & Treagust, 1992; Lee, 2014). Under-generalisation, over-generalisation, and inappropriate common expressions about natural phenomena are some cases of alternative conceptions (Awan & Khan, 2013). Some alternative conceptions do not only lead to inaccurate elucidations being given by students, but have some severe negative impact on the learning process in the sense that the already existing alternative conceptions are used as accommodating frameworks to which new information will be added, leading to lack of conceptual understanding. Conceptual understanding relates to the capacity to understand, interpret, and apply a material that is taught accurately (Retno et al., 2018).

Alternative conceptions that remain unchallenged in the mind of the learner for a long time are most likely to become firmly fixed in the mind

(Gooding & Metz, 2011). The addition of new information in the presence of entrenched alternative conceptions creates a conflict in the students' mind, which perceives the new information to be erroneous, no matter how accurate it is, as long as the new information opposes the existing one. When such a situation arises, the student may try to resolve the cognition conflict either by ignoring the new information, rejecting it, disbelieving it, considering it as irrelevant, reserving it for a later consideration, or reinterpreting it to be consistent with the alternative conception and in other instances, the new information may be accepted with some slight changes in the existing one or the new information may be accepted and the old one being discarded (Eggen, Persson, Jacobsen, & Hafskjold, 2017). This presupposes that once the accommodating framework is wrong, all newly added information will be misinterpreted to be consistent with the existing inaccurate cognition.

Categorisation of alternative conceptions

To break down students' alternative conceptions, teachers need to assist the students to restructure and incorporate their knowledge with incoming information based on scientific models by firstly identifying the alternative conceptions students possess, and creating an enabling environment for the students to confront those alternative conceptions (Gooding & Metz, 2011). It also requires that the teacher possesses some knowledge on alternative conceptions, which includes knowing the various categories (classifications) of alternative conceptions. It is believed that when students' alternative conceptions are properly and accurately categorised, it becomes easier for the teacher to target and attack the sources of those alternative conceptions, and help students overcome them. The National

Research Council [NRC] (1997) categorised alternative conceptions that can hamper learning into five classifications, which are applied in some studies such as Adu-Gyamfi and Ampiah (2019), and Franke, Scharfenberg, and Bogner (2013). Chrzanowski, Grajkowski, Żuchowski, Spalik, and Ostrowska, (2018) refer to the five classifications as the functional type of alternative conceptions.

The five classifications are: preconceived notions, which are the students' ideas obtained from daily familiarities; nonscientific beliefs, which are the ideas of students that are established on the traditions of religion and myths (beliefs) other than scientific principles; conceptual misunderstanding, which emanates from the failure of students' ideas obtained from science lessons in assisting them to antagonise their earlier preconceived notions and nonscientific beliefs; and vernacular misconceptions, which are the inaccurate meanings that students give to scientific words in their daily activities. To throw more light on vernacular misconceptions, Aboagye et al. (2019) articulate that a section of students applies technical terms in unrelated or incongruous contexts. Finally, the fifth category of alternative conceptions based on the NRC's classification is factual misconceptions, which are the persisting students' conceptions that were built on false ideas the students learnt from their early ages of life which have not been confronted till adulthood.

In a study by Hanson (2020), four of the categories of students' alternative conceptions were found as preconceived notions, vernacular misconceptions, nonscientific beliefs and conceptual misunderstandings on some selected chemistry topics which included phase equilibria, solution equilibria, periodicity, hybridisation, stoichiometry, and chemical equilibrium. Students wrongfully described terms connected to the nature of matter, which was suggested that the students probably picked them from everyday usage of language and cultural beliefs. Similarly, in the study by Adu-Gyamfi and Ampiah (2019) on students' alternative conceptions associated with the application of redox reactions in everyday life, three of the categories of alternative conceptions were reported. These were preconceived notions, conceptual misunderstanding, and factual misconceptions. Conceptual misunderstanding recorded the highest percentage of 43.3, followed by factual misconceptions (36.7%) and preconceived notions (20%).

Specific students' alternative conceptions in chemistry

Taber (2019) enlists some examples of common alternative conceptions in chemistry, which are not limited to the thermochemistry concept as follows: despite having different types of magnetism, the term magnetism is often applied to only ferromagnetism which is exhibited by some few elements; and students still think a general property of metals is to be magnetic. Students are of the view that the product of neutralisation reaction must be neutral (neither acidic nor basic). Ordinarily, students have the idea that there is always an active specie that coerces other species to react in chemical reactions. Both students and science teachers may have a conception that the term 'chemicals' is restricted to substances found in the chemical laboratory only. Also, students generally believe that all acids are intrinsically dangerous.

Aside the general chemistry alternative conceptions among students and sometimes teachers, it has been established through research that there are numerous existing students' alternative conceptions on the relationship between chemical reactions and energy (Ayyildiz & Tarhan, 2018). Bond energy, as treated in the context of biological systems, inclines to support the idea that energy is stored in bonds and when the bonds are broken, the energy is then released. This opposes the chemical concept of bond energy, which buttresses the fact that energy is absorbed in the process of breaking bonds (Becker & Cooper, 2014). As Ghanaian SHS science students learn both biology and chemistry, there is a likelihood of transferring knowledge of the biological systems' energy concept into the thermochemistry concept and this will clearly constitute an alternative conception so far as thermochemistry is concerned. Cooper and Klymkowsky (2013) assert that students' notion of bond breaking being accompanied by the release of energy is well-documented. Cooper and Klymkowsky further add that about half of a group of students hold on to the believe that bond breaking releases energy even after they have been taken through appropriate thermochemistry instructions. To many students, energy is needed in the formation of bonds and that energy is released when the bonds break (Cooper & Klymkowsky, 2013). Taber (2019) also reaffirms students' alternative conception on bonds energy by asserting that, students of different ages reflect chemical bonds as a store of energy and consider that the breaking of bonds is accompanied with the release of energy.

The scientifically accepted concept is that energy is released when bonds are formed whereas energy is required in the breaking of bonds. However, students hold on to their alternative conception about bond formation and bond breakage, which is directly opposite to the scientific concept because they might be thinking that energy is contained in bonds. Hence, from the deduction of the students' alternative conceptions, whenever a bond is broken, that energy contained in them must be released rather than viewing it as a process that requires absorption of energy. Similarly, they might be thinking that in bond formation, energy must be absorbed from the universe so that the absorbed energy will hold the bonds strongly together.

In a study conducted by Saricayir et al. (2016) on students' conceptual understanding level of thermodynamics, it was reported that a greater percentage of the students believed that a substance that has higher temperature directly connotes to having higher heat, the total heat of a mixture increases if the total final temperature of the constituents of the mixture is greater than the total initial temperature of those constituents, and the direction of transfer of heat is from a bigger substance to a smaller substance. These conceptions as possessed by the students indicate significant alternative conceptions which others may call as misconceptions among the students.

The ideas expressed by the students are alternative conceptions because heat is thermal energy that is transferred from a hotter body to a cooler body that are in contact. The relationship between heat and temperature is given by the equation $q = m \times C \times \Delta T$, whereby 'q' is heat, 'm' is mass of the substance whose heat is to be determined, 'C' is specific heat capacity of the substance, and 'ΔT' is change in temperature. This suggests that the heat obtained or lost by a body cannot be determined by the measure of its hotness of coldness (temperature) alone (Chang, 2010). Therefore, it is factually incorrect for any person to suggest that a body with higher temperature translates into having a higher heat. The direction of heat flow between any two bodies is not always from the bigger body to the smaller body as the students make it seem as an automatic phenomenon but from the hotter body to the colder body, irrespective of size (Harding, 2018). Moreover, it is inaccurate to suggest that the total heat of a mixture increases if the final temperature of substances that form the mixture is greater than the initial temperature of the substances in that mixture. The resulting heat of a mixture is dependent on the specific enthalpies of the components and the heat of mixing when 1 mol of solution is formed (González, Resa, Concha, & Goenaga, 2004; Shivabasappa, Babu, & Rao, 2008).

Sub-concepts of thermochemistry such as determining the enthalpy change of reactions using the Hess's law of constant heat summation, and the use of data in determining standard enthalpy of formation (ΔH_f^o) are some of the major students' challenges in thermochemistry (Retno et al., 2018). Similarly, Turk and Calik (2008) revealed that students had difficulty in writing enthalpy change signs associated with exothermic and endothermic thermochemical equations. Students also exhibited difficulties in using formulae to calculate enthalpy change values using the standard enthalpy of formation data. Students expressed ideas that the enthalpy change of a reaction is not dependent on the amounts of substances (moles) in the reaction (Wiji & Mulyani, 2018). In another study on identifying students' difficulties in understanding thermochemical materials, students could not identify exothermic and endothermic reactions (Rahmayani, 2017). Students had difficulties in properly applying the concept of conservation of energy in real life situations (Dega & Govender, 2016).

Another revelation made in the study of Rahmayani (2017) was that students could not differentiate heat from temperature. Specifically, Dukhan (2016, p. 3) on framing students learning problems of thermodynamics, asserts that students think of temperature as “a measure of the amount of energy contained in an object”. Most students explain temperature as a measure of the amount of heat possessed by a body (Aboagye et al., 2019). Similarly, Chu, Treagust, Yeo, and Zadnik (2012) articulate that, students consider heat as an intensive quantity and temperature as the amount of heat. Furthermore, students have the ideas that two different temperatures can be summed up and their average calculated, temperature can be transferred from one body to another, heat is proportional to temperature, and hot and cold are different but not at opposite ends of a continuum (Chu et al., 2012). From the foregoing students’ difficulties in thermochemistry, it can be seen that students cannot clearly distinguish temperature from heat as they hold alternative conceptions on heat and temperature.

Students have difficulties with gas law concepts related to pressure, volume, and temperature. Many students fail to take into consideration calculations involving stoichiometry of real gases and express the idea that, irrespective of stoichiometric quantities involved, all gases occupy a volume of 22.4 dm^3. Generally, students exhibit weakness in computational questions that need the application of some conceptual understanding (Sreenivasulu & Subramaniam, 2013). In the study conducted by Wiji and Mulyani (2018), 20.0% of the participants could not manipulate thermochemical equations and compute for enthalpy change values to get the desired answers. This points out the weaknesses of some students in applying mathematical concepts in chemical problems. In that same study by Wiji and Mulyani, students could demonstrate that the enthalpy change of a reaction can be obtained by subtracting the sum of the enthalpies of formation of the products from the sum of the enthalpies of formation of the reactants, but they could not determine the enthalpy change of formation of the substances involved as well as failure to pay attention to the negative and positive signs associated with enthalpy change values.

Factors Accounting for Students' Alternative Conceptions

Since the inception of studies on alternative conceptions, various researchers have gathered a collection of knowledge and intuitions into origin or, otherwise, factors of alternative conceptions. It has been established that, notwithstanding the enlightenments given through theory in school, students continue to develop their misconstructions through the wrongful analyses they give to observable daily occurrences (Schultz et al., 2017). Taber (2019) reports that a leading contributor to one's conceptions is the set of innate knowledge components that link perceptions to acquainted array of knowledge, thereby determining how new experiences are understood. The acquainted array of knowledge acquired by the individual is independent of domain. Hence, the same pre-existing notions are applied in making sense of different areas of experience. However, Gegios, Salta, and Koinis (2017) explain that majority of the alternative conceptions in chemistry do not emanate from the students' unschooled experience of the world, but from curriculum decisions, various pedagogical practices, obscure use of language, and the intangible nature of most concepts of chemistry.

Sources of students' alternative conceptions include the lack of critical observation and appropriate supplementary discussion coupled with inappropriate tuition from teachers, parents, or peers (Adu-Gyamfi & Ampiah, 2019). Osman and Sukor (2013) opine that from theoretical perspective, students' alternative conceptions are constructed from their relations with other people and various learning media. The daily life experiences, traditional instructional language, teachers, mismatches between teacher and students' knowledge of science, changes in the meaning of chemical terms, and textbooks are some factors of students' alternative conceptions (Demircioğlu, Demircioğlu, & Ayas, 2006). In other instances, presenting misleading and erroneous concepts and information also contribute to alternative conceptions among students, and such can be classified as a factors of alternative conception (Schmidt, Marohn, & Harisson, 2007).

Language as source of alternative conception

Science cannot exist without its own language. Therefore, it is imperative for students to know the language of chemistry to enable them to properly understand and express chemical ideas (Quílez, 2019). Meaningful learning in science can be achieved if students are scientifically literate (Retno et al., 2018). Students' scientific language and the use of words that have different literal meaning in everyday life from their scientific meanings contribute greatly to the development of alternative conceptions (Faizal et al., n.d.; Pathare & Pradhan, 2011). For instance, pressure can be defined and used plainly in so many ways. In scientific terms, it is the application of force to a unit area of surface. However, pressure has other literal meanings such as the oppressive condition of physical, mental, social or economic distress. Another literal meaning of pressure is to compel or coerce someone into doing something that they would reluctantly do on their own. Students have been observed to discard the use of scientific words for informal spoken language, which leads to numerous misunderstandings (Mondal & Chakraborty, 2013). Another common example of wrongful usage of scientific language is the frequent use of weight interchangeably for mass and vice versa despite there being a distinction between the two terms. Students tend to apply the everyday layman's usage of such scientific terms in their explanations and that creates alternative conceptions (Mchunu & Imenda, 2013).

Taber (2019) is of the view that individuals attach personal connotations to many terms despite sharing the same language with people within a community. Learners may have poor or misleading meanings for instructional language. Taber adds that in chemistry, it has been found that students sometimes misunderstand both the technical terminologies of chemistry and basic terminology of academic dialogue used in instruction. For instance, students may misunderstand what is intended by terminologies such as negligible, converse, or converge. Therefore, an individual may listen to technically correct statements, but hear something different. The language of chemistry is difficult and that leads to the development of alternative conceptions among students (Hanson et al., 2011).

Faizal et al. (n.d.) articulate that there are some problems where there exist some ambiguities with respect to a specific terminology and language in question. In instances where specific terminologies or scientific terms are not clearly defined, the everyday literal language that has been in existence and used for several years is entrenched in the mind of the student than the new scientific language that has been learnt lately. This leads to the situation whereby the students feel unconfident in using the scientific language with friends and relatives, and so they choose to use the everyday (common) language. The students then use the same common language in explaining scientific phenomena and that contributes to alternative conceptions. For example, students use ‘weight’ instead of ‘mass’ when describing a quantity in the mole concept or using heat to describe the coldness or hotness of a body when actually referring to temperature (Faizal et al., n.d.). In relation to thermochemistry, students have misinterpreted bond breaking mainly from the language point of view which constitutes alternative conception. In a study, students considered bond breaking as a process which involves the release of energy (Ayyildiz & Tarhan, 2012). This interpretation of the students is not wrong in the broader language terms as breaking something could mean setting it loose or free to move. Per such understanding, they are tempted to believe that bond breaking connotes to setting an energy within a bond free to be released. However, such explanation does not situate well in mainstream chemists’ explanations.

Textbooks as source of alternative conceptions

Notwithstanding the increase in availability of electronic media and many digital sources of information, textbooks remain the leading source of information to both students and teachers, and are the most treasured element of curriculum in many countries (Apler, 2019). When suitable teaching materials (including textbooks) are provided, students’ alternative conceptions can be reduced significantly by making the presentation of instructions easier for teachers and at the same time increasing students’ understanding (Retno et al., 2018). Students come across all the new terms and meanings of chemical concepts partly through reading textbooks (Quílez, 2019). Apler (2019) opines that, students spend about 80-95% of classroom time on textbooks, whilst teachers spend 70-90% of classroom time on textbooks. Furthermore, Apler adds that “most of teachers’ instructional decisions are based on textbooks, and students usually absorb all the details in textbooks without doubt” (p. 3).

However, Gegios et al. (2017) claim that in spite of textbooks being the major source from which students gain their knowledge, rigorous scrutiny of textbooks has proven there are features of them that do not expedite comprehension of the contents. Some of those features are that: abridged and insufficient explanations of concepts are often found in chemistry textbooks, attention is given to the quantitative presentation of concepts without providing sufficient qualitative introduction to same, and textbooks make reference to ideas that are not well-grounded in the prototypes scientists have formulated for the study of certain concepts. Concepts presented in some text-books, not limited to chemistry, lack precision and bring up notions that are not conversant to the students, convincing the students to accept those imprecise concepts on trust (Mondal & Chakraborty, 2013). Sanger and Greenbowe (as cited in Osman & Sukor, 2013) report that textbooks contain misleading statements that give a justification for developing alternative conceptions among students. In a study by Vorsah and Adu-Gyamfi (2021) on high school chemistry teachers’ perspectives and practices on teaching mole concept, they also made mention of inappropriate definitions presented in school textbooks which hinder proper understanding and hence, contribute to alternative conceptions among students. Also, students have alternative conceptions about conjugate and non-conjugate acid-base pairs due to the vague descriptions of the two terms in textbooks (Artdej et al., 2010).

The flaws found in textbooks used by students pose a jeopardy to the knowledge that is expected of them to obtain. Instead of students possessing accurate information on scientific concepts, they rather pick up knowledge from textbooks that contradict the accepted ones (Gegios et al., 2017; Osman & Sukor, 2013). Such textbooks are sometimes authored by persons with inadequate understanding of the concepts (Sheehan, 2017). Mostly, books containing these flawed features do not relate prerequisite knowledge to link the new concept, creating a situation of rote learning of vocabulary instead of understanding the concepts (Gegios et al., 2017).

In a study by Rusek and Vojíř (2019), it was found that there are impediments of semantics in lower-secondary chemistry textbooks, which created difficulty in understanding for the students. In another study by Thonney (2016), analysis of science textbooks showed that there were some paragraphs that contained a lot of relatively new technical vocabulary that students had no ideas about. Conducting analyses on readability, content, and mechanical feature analysis of selected commercial science textbooks intended for third grade learners in Philippines, there was an average conceptual problem density of one error in every six to eight pages for four textbooks reviewed, with misidentifications being the common conceptual problems found in the textbooks (Apler, 2019). An inappropriate statement found by Apler in the textbooks reviewed was the statement that all oxygen come from only plants, rather than adding other sources of oxygen which include laboratory preparation methods.

Mondal and Chakraborty (2013) gave some specific examples of misleading statements found in some chemistry textbooks as “when forming ionic compounds, iron gives three electrons”, and “the elementary substance phosphorus consists of four atoms of element phosphorus” (Mondal & Chakraborty, p. 12). In relation to chemical equilibrium, some textbooks contain misleading statements such as the velocities of forward and backward reactions increase evenly when a chemical reaction is about to reach equilibrium and that when a reaction is at equilibrium, concentrations of reactants are equal to concentrations of products (Omilani & Elebute, 2020). Similarly, on the chemical equilibrium concept, Pedrosa and Dias (2000) identified some erroneous statements in textbooks accounting for alternative conceptions such as; a catalyst affects the rate of the forward and reverse reactions differently, no reaction takes place when a reaction reaches equilibrium, and the rate of reaction has the same meaning as the extent of reaction.

Teacher as a factor of alternative conception

Identification and correction of students’ alternative conceptions reside greatly in the teacher (Gooding & Metz, 2011). This requires that the teacher knows what alternative conceptions are and should be able to devise means of eliminating the conceptions among the students. However, it appears some teachers themselves do not know in specific terms what alternative conception is. For instance, in investigating chemistry teachers’ interpretation of some students’ alternative conceptions, Hanson (2020) found out that three out of eleven teachers could not explicitly explain what alternative conceptions are. Specifically, some explained alternative conception as “if students did not understand a topic, then it implied that they had misconceptions”, and “when students are confused, then that could be explained as evidence of misconception” (p. 77). With such inability by teachers to know clearly what alternative conceptions are, it becomes impossible to diagnose students’ alternative conception in order to provide remedies for them.

According to Hanson (2020), teachers accused the ineptitude of some of their colleagues as a contributing factor to students’ alternative conceptions. The accusation was basically premised on the inappropriate instructional strategies used by some teachers. In another breadth, teachers themselves may be uncertain about the knowledge they possess in a concept, yet they proceed to convey it erroneously to their students. Teachers have conceptual difficulties about chemical concepts and this has a consequence on students’ learning results (Anim-Eduful & Adu-Gyamfi, 2021; Vorsah & Adu-Gyamfi, 2021). In organic chemistry, teachers have some conceptual difficulties on the maximum number of bonds a carbon atom can form by conceptualising that carbon atom loses its four outermost electrons so as to achieve the duplet state and become stable (Adu-Gyamfi & Asaki, 2022).

Koc and Yager (2016) claim research has established that many of the common alternative conceptions found among students have also been found among teachers. This presupposes that the alternative conceptions were passed on from the teachers to their students, and the chain of transmission of such alternative conceptions is expected to continue until it is broken somewhere along the line. The manner in which teachers teach can either strengthen or weaken the initial ideas which students come into classroom with. Nonetheless, there are instances whereby teachers’ lessons create a mental chaos and confusions among students (Faizal et al., n.d.). Koc and Yager (2016) further report that most of the participants in their study (preservice teachers' alternative conceptions in elementary science concepts) who exhibited alternative conceptions made mention of their teachers as being the source of their conceptions.

In some instances, teachers use teaching devices such as analogy, models, and metaphors to make abstract concepts conversant to the students, but the students may not regard them as such and rather use those devices as the main concepts that the teacher wants to teach (Taber, 2015). Malcom, Rollnick, and Mavhunga (as cited in Vorsah & Adu-Gyamfi, 2021) claim that inadequate understanding of the mole concept by most teachers could be the reason for students' incapability to understand the mole concept. As asserted by Schoon (1995), it is impossible for teachers to assist their students to confront and revise their alternative conceptions if the same teachers themselves possess similar alternative conceptions as their students. In the study of Schoon (1995), pre-service teachers who were used as participants of the study made mention of hearing their misconceptions from a teacher or a group leader during peer-to-peer study discussions after reflecting on their own alternative conceptions.

Meanwhile, Gooding and Metz (2011) claim that concepts are sometimes introduced to learners without taking cognisance of the state of readiness of learners. Readiness of learners to learn new concepts is a key determinant of learning goals achievement. The manner in which some teachers present lessons also creates a room for students to reduce theoretical knowledge to a factual level and learn them by rote means (Garnett, Garnett,

& Hackling, 1995). If at any point in time students are forced to learn while they are not psychologically ready, the work of the teacher becomes unproductive as those concepts presented to the students will not be learnt properly, or may be learnt by rote means. This borders on instructional delivery approach. Most teachers view the learners as passive recipients of information and present instructional contents to them without giving them the opportunity to contribute to the lesson by sharing their experiences. To this effect, Adu-Gyamfi, Ampiah and Agyei (2020) advocate for the use of participatory teaching and learning approach, which encourages learners to share their respective experiences with their colleagues. With the use of this approach, alternative conceptions can be detected in the experiences of the students and cognitive conflicting strategies can be used to help the students correct their alternative conceptions.

In relation to hybridisation, Hanson, Sam, and Antwi (2012) identified Ghanaian undergraduate chemistry teachers' conceptions on why atomic orbitals undergo hybridisation. They reported some of these alternative conceptions about the prospective chemistry teachers' understanding of the term hybridisation as mixing of two or more electrons, the pairing of more than one atom, overlapping of atoms to form stable bonds among others. Again, on why atomic orbitals undergo hybridisation, some participants expressed ideas that they do so; to obtain inert gas structure or octet rule, to form some bonds, because they contain charged particles, because different orbitals have different energies, to obtain overall stability, to form pi and sigma bonds and their geometry, and because different orbitals have different energy and shape among others. In some instances, most of the prospective teachers either could not correctly answer or failed to provide answers for the types of hybridisation and molecular geometry occurring in SO_2, SO_3, SO_4^{2-}, and SO_3^{2-} as sp^2 (bent), sp^2 (trigonal planar), sp^3 (trigonal pyramidal), and sp^3 (tetrahedral) respectively. The participants suggested that there was a relationship between ionic bonds and hybridisation, all of which were inconsistent with scientific concepts.

Further, teachers need to have a habit of regularly assessing their students to diagnose their learning difficulties. Assessment helps teachers to know the knowledge level of their students as compared to the anticipated knowledge they are supposed to acquire (Barkley & Major, 2015). This can be in the form of giving exercises immediately after delivering a lesson, conducting tests at the end of topics, mid-semester examinations or end of semester examinations. However, assessment should not be conducted at a very later stage. The aim is to detect students' difficulties and use corrective measures to help students overcome those difficulties (Field et al., 2018). Therefore, if the assessment is conducted very late or feedback is not promptly given on students' responses, it becomes difficult and almost practically impossible to correct students' challenges (McClain, Gulbis, & Hays, 2018). When such a habit of regular assessment is inculcated by teachers, effective teaching and learning can be achieved in the classroom.

Everyday experiences as source of alternative conceptions

Sometimes, students' alternative conceptions are based on personal experiences, which may be influenced by their social environments. Students have constructed their own conceptions on different science subjects based on daily experiences and bring these conceptions to the classroom (Franke et al., 2013). These conceptions that are premised on everyday experiences make up preconceived notions category of alternative conceptions (NRC, 1997). Any life experiences and observations gathered in the past by learners is a common source of alternative conceptions (Mchunu & Imenda, 2013) and the accumulation of inaccurate personal experiences result in the formation of alternative conceptions. Hence, Capps, McAllister, and Boone (2013) reiterate that alternative conceptions are said to be borne by daily experiences.

Garnett et al. (1995) are of the view that teachers have no influence or control on the individual's (often inherent) daily experiences that students bring to class. In the absence of analytical and consistent approaches to teaching science and presenting students with the accurate concepts, these inherent students' experiences will mostly lead to creation of conceptions that are inconsistent to scientifically approved concepts. In chemistry, alternative conceptions arising out of daily experiences are given by Garnett et al. as: things get lighter when burnt, and reaction rates increase as the reaction gets going. These conceptions are obviously picked from the observations and experiences of occurrences in the environment, toppled with the individuals' mental explanations given to those occurrences. From daily experiences, students have had the idea that air, which belongs to the gaseous state of matter, is light and massless. This translates to alternative conception in formal instruction as students are found to still hold onto their idea, even after formal instruction, that gas particles do not have mass while in actual fact, gas particles do have mass just as solids have mass (Salame & Casino, 2021). Students might have learnt through experience that an action occurs first before a reaction takes place. This experience might have led students into thinking in the study conducted by Özmen (2007) that forward reaction goes to completion before the reverse reaction starts.

Beliefs as alternative conceptions

Another significant source of alternative conceptions is a person's beliefs that they are exposed to either by their own convictions or influenced by their social environment (Taber, 2019). Even teachers' beliefs about their preferred ways of teaching can influence their teaching behaviours and, in some way, contribute to alternative conceptions (Yang et al., 2014). Schoon (1995) reported in his study that a significant number of the participants, when asked about why they held various alternative conceptions, noted that they had always thought about their conceptions to be true; pointing towards their own beliefs. With environmentally influenced beliefs leading to alternative conceptions, Taber (2019) gives an instance about learners that:

> If they regularly hear references to acids being dangerous, or to there being a hole in the ozone layer, or the term 'chemical' used in a prerogative sense ("I choose organic [sic] foods because they have not been exposed to chemicals"), then they will tend to acquire conceptions from the social milieu which they will at least entertain (and which may provide a unitary conception until formal teaching offers the plurality of a canonical alternative) (p. 8).

Mostly, these beliefs are held unto so strongly that the individual is convicted of them to be the whole truth and show either reluctance or fierce resistance to making corrections about them even when others say something contrary.

Relations of Prerequisite Concepts to Thermochemistry

Alternative conceptions are not just related to non-scientific understanding of one concept, but to several interrelated concepts that can be put together to explain a phenomenon (Lee, 2014). Very necessary prerequisite concepts to learning thermochemistry are particulate nature of matter, periodicity, physical and chemical changes, and chemical bonding (Ayyildiz & Tarhan, 2012). This means that before students can make headways in the study of thermochemistry, they need to properly master the above listed prerequisite concepts. For instance, Sheehan (2017) expresses that chemical bonding is a concept that is necessary and serves as prerequisite to learning concepts such as chemical equilibrium, thermodynamics, organic chemistry, and chemical reactions. It has been established by previous research conducted on students' conceptions that there are many students' difficulties in chemistry. Most of these concepts include atomic structure; chemical equation and formulae; periodicity; chemical bonding (Osman & Sukor, 2013), all of which have relations with the thermochemistry concept.

Garnett et al. (1995) reviewed literature on students' difficulties in chemistry and reported the following on the particulate nature of matter concept. Some students were of the view that one mole of solid and/or liquid has a volume of 22.4 dm^3 at STP. Also captured were that, a particle is a small but visible piece of a substance; all atoms have the same weight; and gas molecules are arranged in an orderly rather than a disorderly fashion. Again, some expressed that heat causes water molecules to expand; melting and boiling of molecular compounds are processes in which covalent bonds within molecules are broken; when a liquid changes to gas, there is a decrease in mass; and gases have no mass (p. 73). In another study concerning the changes of state of matter, common students' difficulties were that bubbles of a boiling water were believed to be comprised of heat, air, oxygen or hydrogen, and steam. Students' difficulties were found to be enormous in condensation than evaporation as they had difficulty in accepting that water in the vapour state can be present in the air (Othman, Treagust, & Chandrasegaran, 2008).

Periodicity is a concept that plays a central role in chemistry. Understanding of periodicity concept enables students to make rational predictions about disparities in atomic size, electron configuration, electronegativity, ionisation energy, electron affinity, effective nuclear charge, melting point, reactivity, and character of elements (Hoffman & Hennessy, 2018). Students conceptualised electronegativity to be a property of an atom that is determined by the number of electrons around the atom (Burrows & Mooring, 2015). To some students, ions with full shells have special inherent stability more than noble gas configurations and a positive nucleus produces a fixed amount of nuclear force that is distributed among the electrons present (Franco-Mariscal, Oliva-Martinez, & Almoraima Gil, 2015).

According to Chang (2010), chemical bonding is an elementary concept that has interrelations with all areas in chemistry. In a study conducted by Ortiz (2019) on students' understanding of the chemical bonding concept using a two-tier instrument, it was reported that only 7.41% of the 28 participants who took part in the study exhibited scientifically correct understanding of chemical bonding, whereas the rest of them either were partially correct by choosing the right option to an item but providing an incorrect explanation to the option selected, or were totally wrong by getting both the options and explanations to the items incorrect. In another study, students were reported to have the conception that shared electron pairs should be centrally located between the atoms forming a bond (Burrows & Mooring, 2015). Some students claim that there are two types of chemical bonds, thus sigma and pi bonds and some think that they are the electrostatic forces that bind the atoms or ions (Meltafina, Wiji, & Mulyani, 2019). In other instances, learners think covalent and ionic bonds are the only types of bonds; regarding metallic and hydrogen bonding as just forces but not actual bonds (Othman et al., 2008). Students also exhibit difficulties in drawing Lewis dot structures of molecules and determination of central atoms in molecules (Uce, 2015). On the concept of hydrogen bonding, Perez et al. (2017) discovered that the students regarded hydrogen bond to be present in any molecule in which hydrogen and any of fluorine, oxygen and nitrogen atoms can be found even if they are not directly bonded. In that same study, students also had the conceptions that the strength of the hydrogen bond increases when there are a lot of hydrogen atoms in a molecule.

Vrabec and Prokša (2016) conducted a research on conceptions related to chemical bonding concepts among students in Slovakia. Their study was a mixed-methods study and included 330 students ageing 15-16 years. It was reported by Vrabec and Prokša that students had the following conceptions about covalent bonding: covalent bonds have very different electronegativity; there is a transfer of electrons in covalent bonding; the covalent bond forms between two electrons; and covalent bonding is formed based on octet rule. In a different study, students expressed ideas that intramolecular forces are broken during melting or boiling; covalent bonds are weak; the difference in states of substances is as a result of difference in the strength of the covalent bonds; and the strength of intermolecular forces is determined by the strength of the covalent bonds present within the molecules (Othman et al., 2008). Furthermore, students think that silicon carbide has a high melting point due to strong intermolecular forces (Barker & Millar, 2000). On ionic bonding, students demonstrate the following alternative conceptions: formation of shared electron pair in ionic compounds; Cl^- gives its electron to the sodium atom to form NaCl; ionic bonding is formed based on octet rule; NaCl is a molecule; the molecules of NaCl form the NaCl structure; and the atoms of Na and Cl attract each other to form NaCl. Thus, students are much thoughtful of the octet rule in explaining chemical bonding despite the many exceptions to it (Croft & de Berg, 2014). In another breadth, students regard molecular iodine as having a metallic bond (Hanson, 2017).

Salah and Dumon (2011) reported on students' difficulties about sp^3 hybridisation in which students conceptualised it to be the merger of s orbital with three p orbitals to produce sp_x, sp_y, and sp_z hybrid orbitals. Again, on molecular geometry, students have had the conceptions that water molecule has a linear geometry; molecular geometry is determined by repulsive forces between bonding electrons and not by non-bonding electrons (Uce, 2015). In relation to the molecular geometry of ammonia, Uyulgan, Akkuzu, and Alpat (2014) reported that a section of the students conceived it to have a trigonal planar shape instead of trigonal pyramidal shape. Özmen, Demircioglu, and Demircioglu (2009) discovered an alternative conception about the shape of the BF_3 molecule. Students in their study had the conception that BF_3 has three bonding electron pairs and one non-bonding electron pair. Therefore, they regarded boron, the central atom in BF_3 molecule, as having a sp^3 hybridisation and would therefore have a trigonal pyramidal shape just like the NH_3 molecule.

The study of Othman et al. (2008) sought to establish the relationship between students' conceptions of particulate nature of matter and chemical bonding and it came out from the study that there was a moderate (magnitude of .42) positive correlation between students' understanding of the particulate nature of matter concept and the chemical bonding concept. Meaning that students who performed well on particulate nature of matter also performed well on chemical bonding. Correspondingly, those who showed alternative conceptions on particulate nature of matter also showed alternative conceptions on chemical bonding. Similarly, Barker and Millar (2000) articulated in their study that there are indeed some correlations between chemical bonding and thermochemistry concepts. They reported that students link chemical bonds to an energy-storing role such as fuels. Since fuels contain energy, students interpreted that, chemical bonds also contain energy and this energy is released when the bond is broken; a conception that is contrary to scientific views.

Conceptual Framework

Identifying students' prior and alternative conceptions and providing remedy for those alternative conceptions leads to a conceptual change (Chrzanowski et al., 2018). The conceptual change then helps to make students' conceptions to be in line with those of mainstream scientists and thus, eliminates alternative conceptions. According to Chrzanowski et al., alternative conceptions can be divided in two types; which are their origin and their functional types (categories/classifications). The onset of the development of alternative conceptions starts with their factors (origin). Teacher factors, textbook factors, language factors, and everyday knowledge are the main causative factors (sources) of students' alternative conceptions. If teachers do not get their pedagogical and content knowledge right, students have difficulty in understanding the language of instruction, textbooks contain misleading statements, and students situate their everyday experiences into complex chemical concepts, then the end result is the possession of ideas that do not conform to scientific concepts (Taber, 2019).

Koc and Yager (2016) report in their study (preservice teachers' alternative conceptions in elementary science concepts) that learners who had alternative conceptions claimed to pick them up from their teachers. Similarly, Vorsah and Adu-Gyamfi (2021) assert that teachers' conceptual difficulties on chemical concepts have adverse effects on students' learning outcomes. In addition, Barkley and Major (2015) and Gooding and Metz (2011) point out teachers' teaching skills and assessment skills respectively as having the potential to let students develop alternative conceptions. Therefore, it is worth noting that a chemistry teacher's knowledge about chemical concepts as well as the teaching skills employed by that teacher have the likelihood of contributing to students' alternative conceptions in the concepts being taught.

Textbooks, being very useful in the teaching and learning process as resource materials, do sometimes come with errors that do not clearly communicate the scientific concepts that readers are supposed to grasp (Apler, 2019). Incorrect definitions, misleading statements, and vague descriptions of terminologies contained in textbooks (Artdej et al., 2010; Vorsah & Adu-

Gyamfi, 2021) partly constitute students' alternative conceptions. Hence, the usage of problematic textbooks is considered as a factor of alternative conceptions which can negatively affect students' scientific understanding of concepts.

It is almost impossible for any individual to be free from miscomprehension, misperceptions or misjudgements that result from the use of language (Wolfram, 2011). Therefore, from Wolfram's position on the use of language, it can be deduced that people, including students, cannot eliminate the possibility of misinterpreting a concept or phenomenon due to how they perceive the language surrounding that phenomenon to be. Page (2012) emphasises that mistaking daily speech lexemes for scientific terms leads to wrongful interpretation of phenomena. Hence, if wrongful interpretations are made due to improper understanding of the language used or application of the daily literal meaning of a word instead of its scientific meaning, that would mean a deviation from what professionals in the field of science have accepted to be right.

In addition, students often gather experiences from their environment either through observation or interactions. As thermochemistry is a practical concept, students may have prior experiences from their environment and go into the classroom with those experiences (Franke et al., 2013). Mostly, the gathering of personal daily experiences are unguided and hence inaccurate deductions on personal experiences may lead to wrongful application of such experiences in explaining thermochemistry concepts, which constitutes alternative conceptions.

Existence of any of the aforementioned factors accounting for alternative conceptions directly affects the students' proper understanding of both the prerequisite and the thermochemistry concepts. If the prerequisite concepts are not properly understood due to alternative conceptions, students are most likely to transfer those conceptions subsequently into learning of the thermochemistry concept. The prerequisite concepts which are particulate nature of matter; atoms, elements, compounds, and molecules; physical and chemical changes; and chemical bonds serve as the foundation for learning the thermochemistry concept (Ayyildiz & Tarhan, 2012). There have been relationships established between interrelated concepts (concepts serving as prerequisites to subsequent ones) in which students who had alternative conceptions in a concept were found to also possess alternative conceptions in its prerequisite or related concept. For instance, the study of Othman et al. (2008) found that there was a moderate positive correlation ($r = .42$) between students' scores in particulate nature of matter and their scores in chemical bonding. This gives an indication that students' understanding of the prerequisite concepts are likely to have a relationship with their understanding of the thermochemistry concept as well as the transfer of alternative conceptions thereof from one concept to another. This is due to the reason that knowledge from the prerequisite concepts will serve as an accommodating framework for the incoming knowledge in thermochemistry (Eggen et al., 2017).

In this study, literature was first reviewed to explore the alternative conceptions of students in thermochemistry, which provided an insight and guidance to construction of the two-tier diagnostic test instrument on thermochemistry. Thereafter, the categories of alternative conceptions identified from existing literature were reviewed, providing an expectation of some possible categories of alternative conceptions that could be found in this study. Subsequently, literature was reviewed to discover the factors of alternative conceptions, which served as a guideline to developing the interview instrument used in this study in probing the factors accounting for the students' alternative conceptions in thermochemistry. It must be noted that, the factors of alternative conceptions are actually what cause the alternative conceptions and other conceptual difficulties (Gegios et al., 2017; Taber, 2019). Therefore, in this study, the factors of alternative conceptions were seen as having a direct effect on the students' understanding of thermochemistry and any alternative conceptions and conceptual difficulties thereof. These factors do not only affect thermochemistry, but the prerequisite concepts as well since the process of learning the various concepts in chemistry may not vary much from one to another.

Finally, literature was reviewed to explore the concepts that serve as a foundation (prerequisite) to understanding thermochemistry and any alternative conceptions that students hold in those concepts. As suggested by literature that there is a relation between the prerequisite concepts and thermochemistry (Becker & Cooper, 2014), some of these relations were explored as well. The relations suggest that students' understanding of the prerequisite concepts tend to positively affect their understanding of thermochemistry (Osman & Sukor, 2013). Similarly, any alternative conceptions and other conceptual difficulties in the prerequisite concepts tend to relate with the alternative conceptions and other conceptual difficulties in thermochemistry. The presence of alternative conceptions in thermochemistry then creates a lack of scientific understanding of the concept among students. The diagrammatic representation of the conceptual framework for this study is presented in Figure 1.

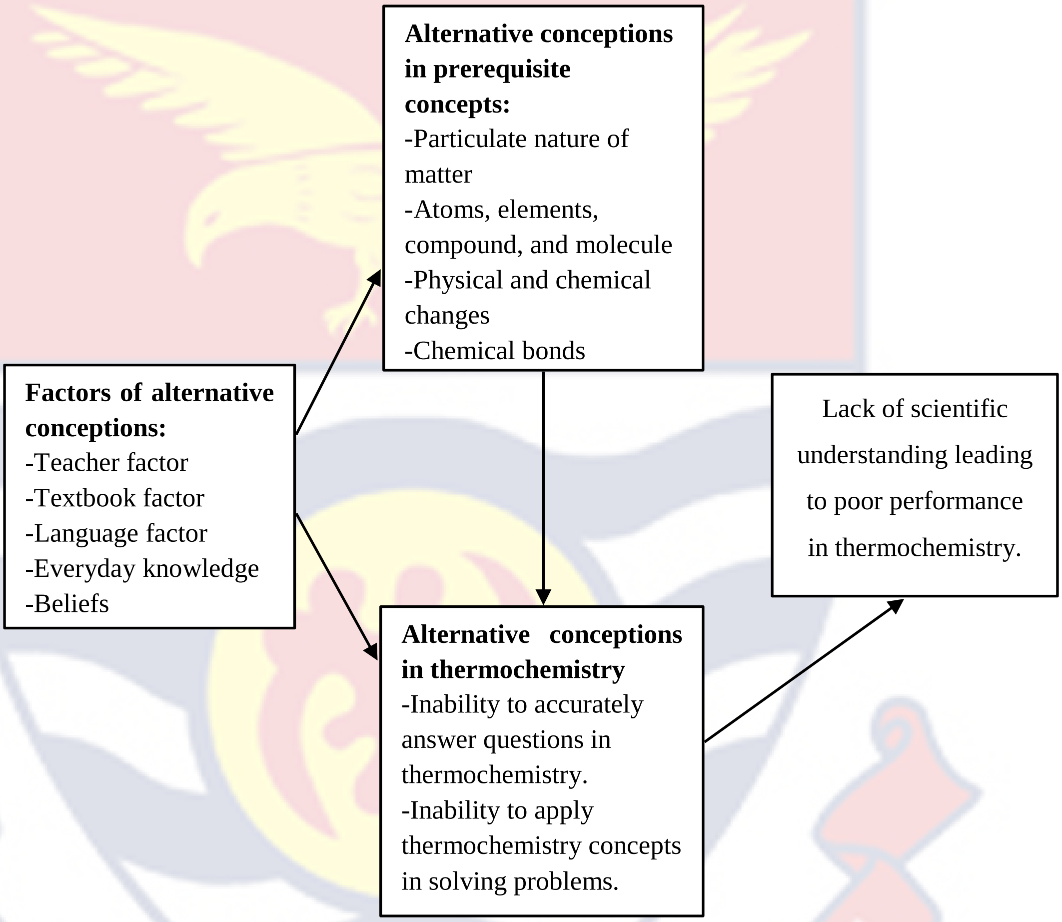


Figure 1: Conceptual framework of the study.

Source: Ofori-Ahenkan (2020).

Summary of Reviewed Literature

This particular chapter (Literature Review) is about the appraisal of existing literature that have relations to this current study. Literature were obtained from sources such as journals, periodicals, textbooks, published theses, and other online publications. Areas on which literature were reviewed included alternative conceptions and conceptual difficulties in thermochemistry, factors accounting for students' alternative conceptions, relations of prerequisite concepts to thermochemistry, and the conceptual framework of the study.

Numerous terms such as misconceptions, children's' science, alternative frameworks, alternative conceptions among others have been used to describe ideas of individuals that are contrary to concepts accepted by the scientific community (Garnett & Treagust, 1992). In respect of that, students' alternative conceptions in thermochemistry have been well documented by some previous studies to include inability to differentiate temperature from heat (Rahmayani, 2017), mistaking endothermic reactions for exothermic reactions and vice versa (Turk & Calik, 2008; Wiji & Mulyani, 2018), conceptualising bond breaking as an energy releasing process (Cooper & Klymkowsky, 2013) and many other conceptions. Some previous research have classified alternative conceptions into five main categories; preconceived notions, nonscientific beliefs, conceptual misunderstandings, vernacular misconceptions, and factual misconceptions (NRC, 1997).

On factors accounting for students' alternative conceptions, literature has indicated that textbooks, teachers, language use, everyday knowledge or experiences, and individual beliefs are major sources of alternative conceptions (Demircioglu et al., 2006; Osman & Sukor, 2013). The prerequisite concepts necessary for learning thermochemistry were identified to be particulate nature of matter; periodicity; physical and chemical changes; and chemical bonding (Ayyildiz & Tarhan, 2012). Some research have reported that students' alternative conceptions in the prerequisite concepts are more likely to be transferred to the thermochemistry concept (Othman et al., 2008).

CHAPTER THREE

RESEARCH METHODS

The current chapter is concerned with describing the research methods that were employed in investigating the conceptions SHS chemistry students have in thermochemistry. The sections in this chapter include the research design, study area, population, sampling procedure, data collection procedure, and data processing and analysis.

Research Design

The purpose of this study was to investigate the conceptions SHS chemistry students have in thermochemistry, which helped in diagnosing the causes of students' alternative conceptions in thermochemistry. Investigating students' conceptions in thermochemistry required a quantitative approach whereas the causes of students' alternative conceptions in thermochemistry were properly diagnosed using a qualitative approach. Therefore, this study was conducted using a mixed-methods approach. The reason for using a mixed-methods approach was that both qualitative and quantitative data were collected in the quest to understanding students' conceptions in thermochemistry.

The mixture of both quantitative and qualitative research approaches was fixed and not emergent in this study because this study was planned from the onset to include the two approaches. Specifically, the convergent parallel mixed methods approach, as a research design, was used for this study. With the use of the convergent parallel mixed-methods design, both the quantitative and qualitative components were executed synchronously within the research process with equal priority given to both strands (Creswell, 2012). Data from the two strands were used to supplement each other in terms of the existing students' conceptions in thermochemistry and the factors accounting for such conceptions. A diagrammatic representation of the convergent parallel mixed-methods design is shown in Figure 2.

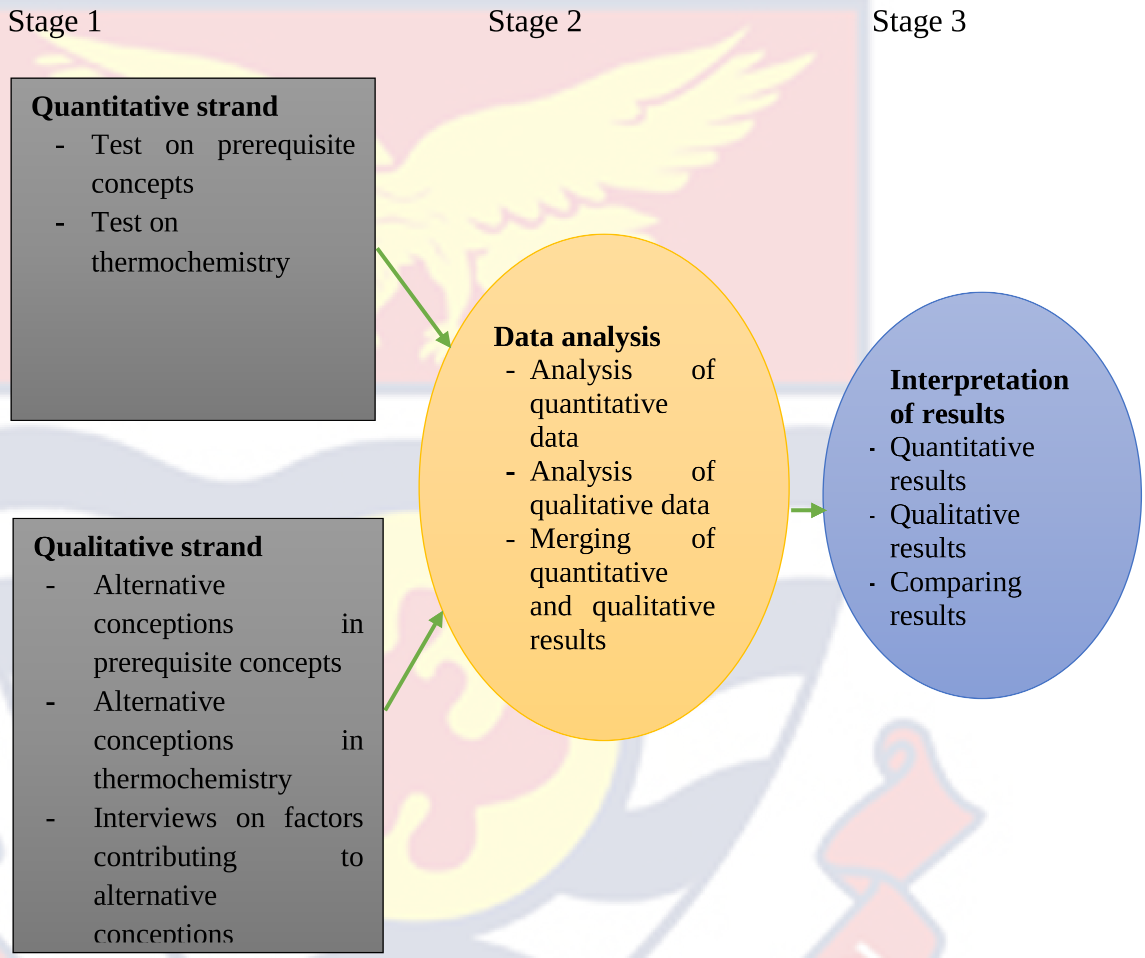


Figure 2: Diagrammatic representation of the convergent parallel mixed-methods design adapted from Creswell (2012).

Stage 1

The quantitative strand of this study was done through the use of two forms of multiple-choice tests in the form of a survey. Employing survey as a tool in administering the tests was informed by its inherent feature of aiding the collection of large numerical data in the form of test scores on the students' performances in the prerequisite concepts relating to thermochemistry. The other quantitative data was on students' test scores on the thermochemistry concept. The qualitative strand was aided by the use of the two-tier diagnostic tests. That is the explanations given by students on the choice of options as answers to the multiple-choice test items were used as the qualitative data on students' conceptions in the prerequisite and thermochemistry concepts. The qualitative data helped to deduce alternative conceptions and other conceptual difficulties students had in thermochemistry. In this study, the other component of the qualitative strand which focused on factors contributing to alternative conceptions was rolled out using the phenomenological approach. The phenomenological approach was used in this study to describe and interpret the experiences of the students as what they perceived were the causes of their alternative conceptions (Ary, Jacobs, & Razavieh, 2010). The use of the approach further helped in obtaining views and experiences of students concerning the underlining factors contributing to their alternative conceptions and other conceptual difficulties in thermochemistry.

Stage 2

In the Stage 2 of the study, the quantitative data collected on students' conceptions on the prerequisite concepts and thermochemistry were analysed separately using descriptive and inferential statistical tools. The alternative conceptions in prerequisite concepts were related to the alternative conceptions in thermochemistry. The qualitative data from the tests and the interviews were also analysed separately using themes from open coding and constant comparison. The two sets of results were merged. This was achieved by comparing the qualitative results with the quantitative one and vice versa. A joint display of array through tables and figures using the quantitative and qualitative results on students' alternative conceptions and other conceptual difficulties and factors contributing to these were presented.

Stage 3

The Stage 3 was the interpretation stage of the study. It was concerned with the way by which findings from both the quantitative and qualitative results were merged (Santos et al., 2017) to properly understand students' alternative conceptions and other conceptual difficulties in thermochemistry. In doing so, interpretations were drawn about the findings from the quantitative results and that of the qualitative results individually. Thereafter, there were interpretations about the similarities and differences in the findings of both qualitative and quantitative results (Rai, 2018). All these helped to draw integrated conclusions on SHS chemistry students' conceptions in learning thermochemistry.

Study Area

The study was conducted in the Cape Coast Metropolis in the Central Region of Ghana. Cape Coast is the capital city of Central Region. The Cape Coast Metropolis shares boundaries with Twifu/Hemang/Lower Denkyira District to the north, Abura-Asebu-Kwamankese District to the east, the Gulf of Guinea to the south, and the Komenda-Edina-Eguafo-Abirem Municipality to the west. The total land area of the Cape Coast Metropolis is 122 km^2. Cape Coast Metropolis has 84 communities. Some notable communities in the metropolis are University of Cape Coast (UCC), Kakumdo, Abura, Pedu, Adisadel village, Aboom, Aquarium, Our Lady of Apostles (OLA) Estate, Effutu, Amisano, Kotokuraba, London Bridge, Chapel Square, Petro, Tantri, Bakaano, Anaafo, and Ekon. The metropolis had an estimated population size of 189,925 (Cape Coast Metropolitan Assembly, 2021) at the time of this study.

The city of Cape Coast is famous for having many of the notable and enviable second cycle and tertiary institutions such as the University of Cape Coast, Cape Coast Technical University, OLA College of Education, the Cape Coast Nursing and Midwifery Training College, St. Augustine’s College, Adisadel College, Mfantsipim Boys School, and Wesley Girls Senior High School. There are a host of second cycle institutions in Cape Coast Metropolis that fall into the three categories of senior high schools (categories A, B, and C) per the GES classification. This made the metropolis a suitable area for conducting this study.

Population

The population for this study was General Science students in all the SHS within the Cape Coast Metropolis. This study targeted General Science students because they study elective science subjects (Biology, Chemistry, Elective Mathematics, and Physics). There were 10 second cycle institutions in the Cape Coast Metropolis that offered the general science programme at the time of conducting this study. Therefore, science students in the 10 schools were targeted in this study. There were three year groups of students in the SHS and based on the chronology of topics in the Ghanaian chemistry curriculum, thermochemistry was not taught in the first year. Therefore, first-year SHS General Science students were not eligible to be included in this study. This made the general science students in SHS 2 and 3 to be the specific group of students who formed the population for this study.

The target population of the SHS 2 and 3 students was estimated to be 5,914 in the 2020/2021 academic year. However, SHS 3 students were preparing for their final year examination (West African Senior School Certificate Examination). For this reason, the SHS 3 students were inaccessible for this study. Also, the SHS 2 Gold Track students were on break and could not be accessible. Thus, the accessible population of students for this study were the SHS 2 Green Track students, totaling 1,634 in number.

Sampling Procedure

A multistage sampling technique was employed in this study. At the first stage, a stratified random sampling technique was used to select three schools among all the 10 schools offering the General Science programme in the Cape Coast Metropolis. From each of the three categories of schools (Categories A, B, C), one school was selected to partake in the study; making the number of participating schools three. This was done to ensure that schools in all the three categories had representations in the sample.

During the second stage, a simple random sampling technique was used to select two second-year science classes from each of the selected schools. This made a total of six general science classes that partook in the study. All the students of a selected second-year science class automatically became subjects of the study. In all, a total of 141 second-year science students were involved in this study. At the third stage of sampling, 12 students (two from each of the six classes) among the 141 students were selected purposively based on the demonstration of high levels of alternative conceptions in thermochemistry for the purpose of conducting an interview with them on the factors accounting for their alternative conceptions. The demographic data of the students are presented in Table 1.

Table 1: Background Characteristics of Students (N = 141)

Variable	F	%
Sex		
Males	92	65.2
Females	49	34.8
School type		
Category A	57	40.4
Category B	45	31.9
Category C	39	27.7
Age		
Below 15	3	2.1
15-17	105	74.5
18-20	26	18.4
Above 20	7	5.0

Source: Field data (Ofori-Ahenkan, 2020).

Of the total number of 141 students, males were 92, representing 65.2%, whereas females were 49, representing 34.8%. Students from ‘Category A’ school were 57, ‘Category B’ were 45, and ‘Category C’ were 39; representing 40.4%, 31.9%, and 27.7% of the total sample size respectively. Among the 141 students, 2.1% were below 15 years of age, 74.5% were in the range of 15-17 years of age, 18.4% were in the range of 18-20 years and 5.0% were above 20 years of age.

Data Collection Instruments

The instruments used in collecting data for this study were tests (test on prerequisite concepts and two-tier diagnostic test on thermochemistry) and interview (interview on factors of alternative conceptions in thermochemistry).

Test on prerequisite concepts (TPRC)

The test instrument on prerequisite concepts was self-constructed to measure the understanding of students on the required concepts that were necessary for learning thermochemistry. The purpose of TPRC in this study was to assess the students' understanding in those concepts to be used to determine whether they had any relationship with the students' conceptual understanding in thermochemistry. TPRC was a two-tier instrument; containing multiple-choice test items and requiring students to provide reasons for the selection of any option under each item. Initially, items were selected from the following concepts with the accompanying number of items from each concept: particulate nature of matter (3), the structure of the atom (4), periodicity (4), interatomic bonding (3), intermolecular bonding (3), and hybridisation and shapes of molecules (3). Thus, there were a total of 20 items on the TPRC (Appendix A) and students were required to answer all the items in a duration of 60 minutes.

Validity for the TPRC instrument was determined by subjecting it to content validity. To ascertain the content validity for TPRC, the items contained in it were thoroughly compared to the concept under study (Bordens & Abbott, 2011). That is, the items in TPRC were compared to their corresponding concepts in the chemistry curriculum to see if the items were directly related to the realisation of the objectives in the curriculum. In addition, each of the items in TPRC was compared to their corresponding concepts in the literature. Lastly, the TPRC instrument was given to some subject matter specialists for critical appraisal and suggestions to fine-tune it.

Reliability of TPRC was done by pilot-testing the instrument on 45 students in a SHS within the Komenda-Edina-Eguafo-Abirem Municipality, who had similar characteristics as the main participants of the study. The internal consistency method was used to check the reliability of the instrument. In order to get a good reliability of the instrument, six of the items were dropped after the pilot-test and that reduced the number of the items from 20 to 14 (Appendix A). Specifically, the Kuder-Richardson 20 reliability index of the instrument with the 14 items was determined to be .70, which according to Howell (2013), was moderately reliable. The items that were dropped were under the following concepts: particulate nature of matter (2), structure of the atom (3), and interatomic bonding (1), The number of items contained in TPRC made it to be brief and prevented the students from losing interest in answering the items. More so, a teaching period in the SHS lasts for 60 minutes. Therefore, answering 14 multiple-choice items with accompanying explanations within these minutes was considered most appropriate. Each correct option selected on any item was scored 1 mark and the corresponding appropriate justification was also scored 1 mark; making the score for each item 2 marks. Thus, the maximum marks students could gain in TPRC was 28.

Two-tier diagnostic test on thermochemistry (TTDTT)

TTDTT contained two-tier diagnostic test items. That is, there were multiple-choice items with four options of which students were to select one as the correct response. There was also an additional space for students to provide reasons for the choice of an option selected. At the initial stage of constructing the instrument, the items were sampled from the following sub-concepts of thermochemistry: energy and enthalpy (2), endothermic and exothermic processes (3), energy in food and fuels (3), standard state and standard enthalpy change of reactions (3), enthalpy change of a reaction (3), enthalpy of neutralisation of an acid-base reaction (2), Hess's law of heat summation and the Born-Haber cycle (2), and bonds energy (2). These selections made a total of 20 items. However, the items were reduced to 15 after pilot-testing (Appendix B). The four options under each item included one correct response and three distractors. The distractors among the options to each item were carefully selected such that they would look more appealing to students who had partial knowledge in thermochemistry about the items (Gierl, Bulut, Guo, & Zhang, 2017; Muntholib, Pratiwi, Muchson, & Yahmin, 2018). Scoring of items in TTDTT was done in the same way as scoring was done in TPRC since they both had the same format.

Validity of TTDTT was determined through content validity and critical appraisal by a subject matter specialist in a similar manner as the validity for the TPRC was determined. The TTDTT was also pilot-tested on 45 students in the Komenda-Edina-Eguafo-Abirem Municipality.

Reliability of TTDTT was determined by using the internal consistency method. This yielded a Kuder-Richardson 20 reliability index of .80 after doing the reliability analysis. This means that the final TTDTT instrument, containing 15 items after five items that were too difficult or easy were dropped to enrich its reliability, was found to be very reliable (Howell, 2013). The following were number of items and sub-concepts under which items were deleted; energy and enthalpy (1), endothermic and exothermic processes (1), energy in food and fuels (1), and bonds energy (2). Again, students were allowed a maximum of 60 minutes to respond to the 15 items in TTDTT.

Interview on factors of alternative conceptions in thermochemistry (IFACT)

IFACT was an interview guide that was self-constructed by the researcher. It was used to achieve some part of the qualitative aspect of this study. IFACT was developed using the standardised open-ended interview approach. The questions that were to be asked and the order in which the questions were to be asked were planned ahead of the interview date. The wordings of the items were personalised such that they directly addressed the students. There were five items in IFACT (Appendix C).

Validity of IFACT was ensured using the independent observer analysis approach. This was done by involving other independent observers and asking them whether they would have seen or heard the same things as the researcher would have seen or heard, and if so whether they would have made theoretical findings that logically would corroborate the researcher's conclusions. The responses of the independent observers suggested the authentication of the researcher's conclusions. Furthermore, the violation of investigator bias, misperceptions of investigator, and misunderstanding on the part of students were checked. Bias was reduced by avoiding the seeking of questions and answers that supported the researcher's preconceived ideas about causes of students' alternative conceptions. Again, misperceptions on the part of the researcher concerning what the students said were avoided by making sure their responses were not misconstrued. Also, it was ensured that the students truly understood the questions that they were asked before they answered them.

Reliability of IFACT was ensured by using the outside audit method. By this method, the supervisor of this research reviewed the data collection and analysis procedures documented in this study. On the basis of this audit, the procedures used were pronounced as appropriate within the ambit of accepted good practice and they were also pronounced as being properly carried out.

Data Collection Procedures

Data collection in this study was done within a duration of three weeks. Prior to going to the field for data collection, contacts were made with the heads of the selected schools in which data were collected. The purpose of the study was explained to the heads of the schools and their permissions were sought to allow for the collection of data from their schools. After permission was granted by the heads of the schools, contacts were made with the heads of science departments and chemistry teachers in the schools. They made arrangements for the dates and times at which data collection would be suitable and appropriate in order to minimise the interruption of their scheduled academic work. Efforts were then made to visit the schools at the scheduled times for data collection. The purpose of the study was communicated clearly to the students in the selected classes and they were assured that the study was purely for academic purposes and that their identity would be kept hidden. Again, students were informed that their participation in the study would be voluntary and that they could opt-out of the study as and when they felt the need to do so.

In the first week of data collection, copies of the TPRC instrument were distributed to the students and they were allowed to respond to the items for a period of 60 minutes. The responses were then collected after the 60-minute duration. Afterwards, the students were informed about the administration of the TTDTT instrument and the concepts that it would cover, which was slated for the following week (second week) of data collection. In the second week, copies of the TTDTT were distributed to the students to respond to the items. A duration of 60 minutes was allocated to responding to the items on TTDTT. Since each student responded to both the TPRC and TTDTT, the responses provided by any particular student to both instruments were compared. To make this possible, the participating students were given unique codes during the administrations of both the TPRC and TTDTT. The unique codes were then used to make the sorting of test sheets belonging to each student easier. For instance, a student with a unique code of ‘STC01’ had to write this same code on both of their TPRC and TTDTT test sheets.

In collecting data for answering the research question on factors accounting for alternative conceptions in thermochemistry, 12 students were selected purposively based on the demonstration of high levels of alternative conceptions on thermochemistry and engaged through an interview. All the responses were recorded using a tape recorder for later playback and subsequent transcription. The interviews took place in the third week of data collection.

Data Processing and Analysis

The processing of quantitative data in this study involved the scoring of multiple-choice test items on both TPRC and TTDTT. Afterwards, the papers were sorted out such that both the TPRC and TTDTT responded to by each of the students could be identified to allow for comparison between their scores and reasons provided to establish the presence of any alternative conceptions. Both tests were scored by giving two marks for selecting the correct option as well as providing the appropriate explanation to an item, one mark for being able to select the right option but failing to provide the appropriate explanation, and zero mark for failing to provide both the right option and explanation to an item. The scores were then grouped as 'full understanding' for scoring the maximum two marks on an item, 'partial understanding' for scoring one mark, and 'no understanding' for scoring zero mark on an item.

In analysing data for answering the first research question (categories of students' alternative conceptions and other conceptual difficulties in thermochemistry), the percentages of students' scores obtained on each item; grouped as full understanding, partial understanding and no understanding, together with the difficulty indices of the items in TTDTT were calculated using frequencies and percentages, and presented in a table. Thereafter, students' explanations that were regarded as alternative conceptions and conceptual difficulties were presented for each item. Then, the identified alternative conceptions were openly coded and constantly compared across all the students to make way for the generation of categories of the alternative conceptions according to the NRC (1997) classifications. To buttress the basis for the selection of categories, some of the individual responses falling under each of the categories were presented. The percentage occurrences of each category of alternative conceptions were presented in a bar chart and subsequently discussed.

Data on the second research question (factors that account for students' alternative conceptions in thermochemistry) were analysed using the thematic analysis approach. Thematic analysis in this study was done by reading the responses gathered through the use of IFACT and grouping the responses under major themes and sub-themes. To do the grouping of responses into themes, commonalities in the views expressed by the students with respect to each item were established and such common views were placed into groups that represented unifying ideas. Maximum and equal attention was given to all data in order to key in very relevant aspects of the data that constituted the basis for themes across all data set. Specifically, the recorded voices of the 12 interviewees were transcribed by playing the voice notes and writing the exact responses on paper. This was then followed by familiarisation with the data. At the familiarisation phase, all the responses on all items were read for at least twice in order to be cognisant of the responses provided. After familiarisation with the data, codes were generated by using very brief phrases to represent bits of data (coding) that were relevant to answering the research question. These codes were semantic codes, otherwise known as data-derived codes. The next thing that was done was to search for themes by carefully examining all the data-derived codes to identify all those that had similar connotations. Codes with similar inferences were then grouped into sub-themes. Also, all sub-themes that pointed to similar directions were clustered into major themes. This was followed by the review of potential themes, which involved the thorough re-examination of the ideas that went into the selection of sub-themes and major themes to ascertain whether the themes should be maintained or changed to have a better reflection of the objective of the research question. Afterwards, the reviewed themes were defined and named. This involved a description of the uniqueness and specificity of each of the themes to ensure that all themes had singular focus each, were related but not repetitive of one another, and directly addressed the research question. In order to ensure the reliability of the results and reduce researcher bias, an expert (the supervisor of this study) reviewed the analysis procedure and how the codes, sub-themes and major themes were obtained and certified them as appropriate. Finally, the findings were presented in the narrative form according to the major themes, with their sub-themes and excerpts of the interview, and discussed in relation to existing literature.

With regard to answering the third research question, students' scores on TPRC were presented in a table under the groupings of full understanding, partial understanding, and no understanding using frequencies and percentages. Students' alternative conceptions and other conceptual difficulties under each item were then identified and presented. Again, the identified alternative conceptions in the prerequisite concepts were categorised and the percentage occurrence of each category were presented in a bar chart. Thereafter, the Pearson product-moment correlation (r) was used to find the relationship between students' achievement in the prerequisite concepts and thermochemistry. This analytical tool was used as the intention was to establish an association between two continuous variables (test scores)

(Pagano, 2013). The Pearson product-moment correlation was considered as the appropriate tool to use in establishing the relationship as the data satisfied all the assumptions associated with the use of the tool. That is, the variables measured were continuous. Also, there were related pairs of variables as each participant had scores on both the prerequisite concepts and thermochemistry. The data were normally distributed. In addition, there was linearity (straight line relationship) among the variables. Furthermore, the alternative conceptions that were exhibited by the students in TPRC were categorised based on the NRC (1997) classification and compared to the categories of alternative conceptions that were obtained from TTDTT. Hence, it was made easier to conclude whether students' achievement in the prerequisite concepts was likely to have an association with their achievement in the thermochemistry concept. The unit of data analysis was the students.

CHAPTER FOUR

RESULTS AND DISCUSSION

The study aimed at investigating students' conceptual difficulties in thermochemistry. This chapter is concerned with the presentation of results and discussion of findings. The results and discussion of findings are presented under each research question. Quantitative results containing numerals are presented in tables and figures, whereas qualitative results are presented in the narrative form using the themes as guide.

Categories of Students' Alternative Conceptions and other Conceptual Difficulties in Thermochemistry

The aim of the first research question was to explore the categories of students' alternative conceptions and other conceptual difficulties in thermochemistry. This research question was probed in three sections as; analysis of the students' conceptual difficulties in relation to their scores on each item in TTDTT, establishment of alternative conceptions in thermochemistry, and categorisation of the identified alternative conceptions based on the NRC (1997) categories of alternative conceptions. To analyse the conceptual difficulties of the students in the thermochemistry concept, the items in TTDTT were scored to obtain the number of students having either full understanding, partial understanding or no understanding of each item. Results of the analysis of the students' understanding of thermochemistry are presented in Table 2.

Table 2: Students' Understanding of Thermochemistry Concept (N = 141)

Item	Full Understanding		Partial Understanding		No Understanding		Difficulty Index
	N	%	N	%	N	%	
1	51	36.2	5	3.5	85	60.3	.36
2	23	16.3	3	2.1	115	81.6	.16
3	80	56.7	46	32.6	15	10.6	.57
4	33	23.4	11	7.8	97	68.8	.23
5	29	20.6	4	2.8	108	76.6	.21
6	14	9.9	13	9.2	114	80.9	.10
7	37	26.2	18	12.8	86	61.0	.26
8	56	39.7	34	24.1	51	36.2	.40
9	26	18.4	28	19.9	87	61.7	.18
10	46	32.6	45	31.9	50	35.5	.33
11	35	24.8	14	9.9	92	65.2	.25
12	70	49.6	46	32.6	25	17.7	.50
13	15	10.6	2	1.4	124	87.9	.11
14	40	28.4	39	27.7	62	44.0	.28
15	43	30.5	31	22.0	67	47.5	.31

Source: Field data (Ofori-Ahenkan, 2020).

On Item 1, the results showed that students had conceptual difficulties on the meaning of enthalpy of neutralisation reaction. This is because the item difficulty index was estimated as *.36* with only 36.2% of the 141 students demonstrating full scientific understanding of the concept. That is, 60.3% of the students had no scientific understanding that the enthalpy of neutralisation reaction is always less than zero. Some alternative conceptions and other conceptual difficulties were found in the explanations of the students who could not show the scientific understanding of the item.

Alternative conceptions: Among the explanations provided on this item, 44.7% of them were alternative conceptions. For instance, some of the students explained that neutralisation reactions are always endothermic. An excerpt is:

> "*Neutralisation reaction involves the combination of acid and base to form salt and water. Energy is needed to overcome the hydration energy before the reaction can occur. Thus, the reaction is always endothermic and its enthalpy is always greater than zero*" (STC012).

Stoichiometric amounts of reactants account for positive enthalpy of a neutralisation reaction. An excerpt is:

> "*The enthalpy of neutralisation is always greater than zero because both reactants are consumed in same amounts or units*" (STC037).

The charges of H^+ and OH^- cancel out in a reaction of acid and base, hence neutralisation reactions have zero enthalpy. An excerpt is:

> "*This is because the enthalpy of neutralisation is when 1mol of* H^+ *ions from an acid reacts with* OH^- *ions from an alkali to produce* H_2O *molecules under standard conditions. The charges cancel out making it zero*" (STC089).

Neutralisation reaction between a strong acid and strong alkali is exothermic, whereas the reaction is endothermic for weak acid and weak base. An excerpt is:

> "*Neutralisation reaction between strong acid and strong base always releases energy into the surrounding, therefore, its enthalpy is less*

> *than zero but for weak acid and a strong base, they absorb heat to dissociate completely to form water. Therefore, its enthalpy is greater than zero irrespective of the energy absorbed to dissociate completely to form water*" (STC050).

A neutralisation reaction can either be endothermic or exothermic based on the mole ratio. An excerpt is:

> "*The reaction heat of acid and base is less than or greater than zero because the mole ratio differs*" (STC098).

The enthalpy of a neutralisation reaction is zero because there is no energy change. An excerpt is:

> "*When it is less than zero, then the reaction is exothermic and when it is more than zero, then the reaction is endothermic but when it is exactly zero, then it means no reaction took place because there was no energy change*" (STC077).

Other conceptual difficulties: Among the explanations given, conceptual difficulties constituted 19.1% of them. For instance, some of the students could not conceptualise that an occurring reaction can either be endothermic or exothermic and nothing in-between the two. An excerpt is:

> "*This means that in the reaction between 1 mole of an acid with 1 mole of a base to form 1 mole of water, there is no heat lost or heat gain. Hence the enthalpy is always zero*" (STC052).

Some of the students could not differentiate neutralisation reaction from combustion reaction. An excerpt is:

> "*This is because the substance burns completely in O_2 that is oxygen gas which is exothermic so its substance heat is always given out.*

> *Therefore, the enthalpy of combustion is negative and less than zero*” (STC083).

With regards to Item 2, the difficulty index was *.16*, indicating that it was very difficult for the students to conceptualise that all of the energy can be accounted for when energy is changed from one form to another. This indicated that only 16.3% of the 141 students demonstrated full scientific understanding related to conservation of energy in a chemical reaction, while 83.7% of the students had no scientific understanding of that. Among the explanations provided to this item by the students who were found to have no scientific understanding of it, some alternative conceptions and other conceptual difficulties were identified.

Alternative conceptions: Of the explanations provided on this item, 14.1% were alternative conceptions. For instance, some of the students had the conception that change in state of substances leads to a loss of energy. An extract is:

> “*Some of the energy is lost entirely because when elements in their standard states are changed from one form to another, their qualities are lost, therefore the energy is also lost*” (STC003).

Other conceptual difficulties: The conceptual difficulties constituted 69.6%. For instance, some of the students had difficulties in conceptualising that energy transformation is independent of the changes in physical states of substances. An excerpt is:

> “*A physical change has occurred because taking into consideration when heat energy is transferred into light energy, we obtain a physical*

> *change and even when something is being burnt the thing gets to ashes and that also gives us another physical property*" (STC013).

Some of the students had difficulties in hypothesising that molecules can be excited without necessarily changing their physical states. An extract is:

> "*Change in energy reduces or increases the activeness of molecules, causing some physical changes to occur*" (STC020).

Some of the students could not use chemical concepts to explain transformation or conservation of energy. An extract is:

> "*… a goat chews grass and a human being also kills the goat and eat. The energy the goat had from the grass some of the energy will be used by the goat*" (STC033).

Item 3 had a difficulty index of *.57*, meaning that it was moderately easy for the students to conceptualise that the reaction was exothermic and therefore, heat was released. This showed that 56.7% of the 141 students exhibited full scientific understanding related to the type of reaction that occurred between aluminium and oxygen, while 43.2% of the students had no scientific understanding of that. Among the 43.2% of the students who had no scientific understanding of the item, some alternative conceptions and other conceptual difficulties were identified in their explanations.

Alternative conceptions: Among the explanations given, 32.4% were alternative conceptions. For instance, some of the students had alternative conceptions that all exothermic reactions are accompanied by exchange of heat and mass to the surrounding. An extract is:

> "*It means in the reaction, there was exchange of both heat and mass to the external environment and hence heat was released to the surrounding*" (STC052).

Endothermic reactions have negative enthalpy values. An extract is:

> "*This is because the energy change of every endothermic reaction is negative*" (STC020).

Energy is a form of force. An excerpt is:

> "*This is because energy is being used in a form of force and whenever force is applied there will be a physical change*" (STC116).

Combustion reactions involve the absorption of heat. An extract is:

> "*This is because the energy involved in the combustion reaction will be absorbed*" (STC009).

Other conceptual difficulties: Of all the explanations given to this item, 10.9% were conceptual difficulties. For instance, some of the students knew from the enthalpy change value associated with the reaction that it was exothermic but had difficulties in hypothesising that the reaction was a combustion reaction and so energy would be released. An excerpt is:

> "*The negative enthalpy value implies that the reaction is exothermic hence heat is released*" (STC089).

Some of the students could not comprehend that the enthalpy change value given along with the reaction was for the entire reaction and not the product only. In other words, the students thought the enthalpy change value of the reaction was the standard enthalpy of formation of the product. An excerpt is:

> "*The reaction is exothermic because the enthalpy of the products formed is negative*" (STC100).

A group of students had difficulty in determining that the reaction was exothermic. An excerpt is:

> "*Endothermic reactions occur internally and absorb energy at the end of the reaction process*" (STC037).

For Item 4, the difficulty index was determined to be *.23*, indicating that it was quite difficult for the students to conceptualise that water vapour condenses to give liquid water and heat is released. Of the 141 students, 23.4% exhibited full scientific understanding, while 76.6% exhibited no scientific understanding of the equation for condensation of water. Some alternative conceptions and conceptual difficulties were found among the explanations of the students who had partial understanding and no scientific understanding of the concept.

Alternative conceptions: Students' explanations constituting alternative conceptions on Item 4 were found to be 56.4% of all the explanations given. For instance, some of the students had the conceptions that condensation involves the application of heat. An excerpt is:

> "*Condensation is the process by which gaseous substances change to liquid by the application of heat*" (STC004).

Gaseous water molecules break down to form liquid water when heated. An excerpt is:

> "*When gaseous H_2O is heated the molecules breakdown to form liquid H_2O*" (STC045).

Heat is produced rather than being given off during condensation. An excerpt is:

> "*In condensation, water vapour changes to liquid state and heat is produced*" (STC032).

Applying heat to water makes the water to condense. An excerpt is:

> "*…when heat reacts with water the heat condenses its water into the gaseous form*" (STC009).

Other conceptual difficulties: Conceptual difficulties constituted 20.2% of the explanations provided to Item 4. For example, some of the students exhibited lack of understanding on condensation through the inability to differentiate between vapourisation and condensation. An excerpt is:

> "*This is because in the condensation of water, heat is needed to change H_2O liquid to H_2O gas*" (STC113).

In relation to Item 5, the difficulty index was *.21*, which indicated that the concept was very difficult for the students to conceptualise that the volume of 2 mol of H_2 gas reacting at standard temperature and pressure (STP) is 44.8 L. Only 20.6% of the 141 students showed full scientific understanding of the volume occupied by 2 mol of H_2 gas at STP, whereas 79.4% of the students had no scientific understanding of that. Some alternative conceptions and other conceptual difficulties were found in the explanations of the students who showed partial and no scientific understanding of the concept.

Alternative conceptions: From the explanations given to the item, 37.9% were alternative conceptions. For instance, some of the students had the conception that the volume of any ideal gas at STP is 22.4 L irrespective of the number of moles involved. An excerpt is:

> "*The volume occupied by any moles of any substance is 22.4 dm^3 (i.e., 24L) at standard temperature and pressure*" (STC049).

Other conceptual difficulties: From the explanations given on Item 5, 41.9% were other conceptual difficulties. For instance, some of the students had difficulty in applying the concept of molar volume in explaining their answer. An excerpt is:

> "*155 kJ – 310 kJ = 15*" (STC005).

On Item 6, the results showed that students had alternative conceptions and other conceptual difficulties on the enthalpy change between PCl_5 and H_2O. This is because the item difficulty index was found to be *.10*, indicating that it was very difficult for the students to conceptualise that 72 kJ of energy was released in the reaction. Of the 141 students, only 9.9% demonstrated full scientific understanding of the concept, whereas 90.1% of the students had no scientific understanding of it. Some alternative conceptions and other conceptual difficulties were identified in the explanations given by the students who had partial understanding and no scientific understanding of the concept.

Alternative conceptions: Among the explanations given, 39.6% were alternative conceptions. For instance, some of the students had the conception that enthalpy change for the reaction would be positive due to the release of energy. An excerpt is:

> "*Since energy is released in this reaction, the enthalpy change will be positive. The enthalpy change +230 kJmol^{-1} is as a result of dividing the energy released by the amount of PCl_5 which reacted with four moles of water*" (STC018).

Also, heat is absorbed in the reaction as opposed to heat being released. An excerpt is:

> "*It means 230 kJ/mol is absorbed in the reaction…*" (STC052).

Other conceptual difficulties: Of all the explanations provided to this item, 50.5% were other conceptual difficulties. For instance, some of the students had difficulty in presenting the final answer to rightly depict that the reaction was exothermic, even when it was stated that energy was released in the concept. An excerpt is:

> "*n(PCl_5) = 65/208 = 0.3125mol. 1mol = ?; 0.3125mol = 72 kJ; this implies 72 kJ / 0.3125mol = +230 kJ/mol*" (STC001).

Some of the students could not rightly demonstrate how to calculate for the enthalpy change. An excerpt is:

> "*n = m/Mr; n = 65/208; n = 0.3125mol; if 72 kJ = 0.3125, then x = 1 mole. x/72 = 0.3125; this gives x = 22.5 kJ*" (STC012).

Some of the students were unable to express what was needed to be done in solving the given problem. An excerpt is:

> "*The reaction equation will be reversed and divided by the moles to get the enthalpy change of the reaction*" (STC036).

Results on Item 7 indicated that students had both alternative conceptions and other conceptual difficulties in relation to the Hess' law of heat summation. The item difficulty index was estimated to be .*26*, indicating that it was difficult for most of the students to conceptualise that the reaction occurred through two separate steps and that the enthalpy for the net reaction was -792 kJ/mol. Of the 141 students, only 26.2% had a full scientific understanding of the concept while 73.8% had no scientific understanding of it.

Alternative conceptions: Of the explanations given to the item, 34% were alternative conceptions. For instance, some of the students had the conception that the reaction was endothermic with an enthalpy change of +396 kJ/mol. An excerpt is:

> "*It means the reaction is endothermic. Which means 396 kJ is absorbed per mole*" (STC108).

The reaction was not feasible at STP. An excerpt is:

> "*The reaction does not occur at the STP*" (STC115).

Heat was gained and hence, the reaction was endothermic. An excerpt is:

> "*Per every mole the heat gain is +396 kJ/mol. Therefore, the reaction is endothermic reaction*" (STC122).

Other conceptual difficulties: Out of all the explanations provided to the item, 39.8% were other conceptual difficulties. For instance; some of the students had difficulties in manipulating the reaction steps 1 and 2 to get the overall reaction, $2S_{(s)} + 3O_{2(g)} \longrightarrow 2SO_{3(g)}$. An excerpt is:

> "*Reverse equation (2)*[$2SO_{2(g)} + O_{2(g)} \longrightarrow 2SO_{3(g)}$; $\Delta H_{rxn} = -198$ kJ/mol] *and multiply equation (1)* [$S_{(s)} + O_{2(g)} \longrightarrow SO_{2(g)}$; $\Delta H_{rxn} = -297$ kJ/mol] *by 2, resulting to -396 kJ/mol as the enthalpy change for the net reaction*" (STC007).

On Item 8, a difficulty index of .*40* indicated that the concept was a little difficult for majority of the students to conceptualise that the standard enthalpy of the decomposition of ammonia was +92.6 kJ from the reaction equation and the corresponding enthalpy change given for the formation of ammonia. Of the 141 students, 39.7% showed full scientific understanding of the concept, whereas 60.3% had no scientific understanding of it. In the 60.3%

of the students' explanations related to the enthalpy of decomposition of ammonia that were regarded as partial understanding and no scientific understanding, some alternative conceptions and other conceptual difficulties were identified.

Alternative conceptions: Of the explanations given to the item, 47.2% were alternative conceptions. For instance, some of the students had a conception that the enthalpy change of the reaction would remain the same (-92.6 kJ/mol) according to Hess' law of heat summation. An excerpt is:

> "*Hess's law of constant heat summation states that the enthalpy change when a substance is formed form different steps is always constant irrespective of the individual steps. The above shows the formation of ammonia in different steps hence* ΔH_f *= -92.6 kJ/mol*" (STC055).

Also, bond formation is endothermic and bond breaking is exothermic. An excerpt is:

> "*Since the reaction (exothermic reaction) is reversed, the enthalpy of formation of* NH_3 *is endothermic. Heat is absorbed by the reactants to form the product [formation of ammonia from hydrogen and nitrogen gases] unlike 1st equation [decomposition of ammonia] where heat is released to break* NH_3 *into its various components*" (STC031).

Enthalpy change would be zero when the enthalpies of the reactions leading to the formation of the overall reaction cancel out. An excerpt is:

> "*The* ΔH^o *for the reaction is zero because the enthalpies of the reactions cancel out*" (STC096).

Ammonia was taken from the product side to the reactant side; hence the enthalpy of the reaction would change. An excerpt is:

> "*Since the product was sent to the reactant side, the state of the reaction will change from exothermic to endothermic*" (STC035).

Other conceptual difficulties: The composition of the explanations classified as other conceptual difficulties were 13.1% of all the explanations provided to the item. For instance, some of the students had difficulty in differentiating the enthalpies of elements in their standard states from the decomposition of ammonia. An excerpt is:

> "*Since the standard enthalpy change of an element in its standard state is zero, there is a liberation of 185.2 kJ of heat after the reaction*" (STC087).

The results on Item 9 indicated that there were alternative conceptions and other conceptual difficulties related to the Born-Haber cycle. The difficulty index of *.18* indicated that it was very difficult for most of the students to conceptualise that the electron affinity of chlorine (Cl) was Step Z in the Born-Haber cycle for NaCl as shown in the diagram presented along with the item. Of the 141 students, only 18.4% showed full scientific understanding of the concept, whereas 81.6% showed no scientific understanding of it.

Alternative conceptions: Of all the explanations given to this item, 67.1% were identified as alternative conceptions. For instance, some of the students had the conception that chlorine was unstable because it was in the gaseous state, hence accept an electron to be stable. An excerpt is:

> "*$Cl_{(g)}$ is in the gaseous state and unstable and therefore has to gain an electron in order to become stable. $Cl_{(g)} \longrightarrow Cl^-$ is the process leading to the gain of the electron needed that is the first electron affinity of chlorine*" (STC025).

Also, chlorine loses an electron to attain a charge of -1. An excerpt is:

> "*Since the charge on Cl^- is -1, it means it lost an electron*" (STC129).

Electron affinity precedes enthalpy of ionisation. An excerpt is:

> "*This is because in the Born-Haber cycle it comes in stages and the electron affinity comes first followed by the enthalpy of ionisation*" (STC013).

Gaseous chloride ion will undergo combustion with the sodium ion. An excerpt is:

> "*The electron affinity of $Cl_{(g)}$ is represented by letter Z, which indicate the $Cl_{(g)}$ will burn with Na^+ containing +1 charge*" (STC034).

Some of the students explained enthalpy of ionisation without having regards for the gaseous state of the atoms. An excerpt is:

> "*The enthalpy of ionisation is the energy required to remove one mole of an electron from the outermost shell of an atom to form one mole of a singly charged cation*" (STC031).

Other conceptual difficulties: The composition of explanations identified as other conceptual difficulties was 14.5%. For instance, some of the students had difficulty in differentiating electron affinity from lattice energy and, at the same time, could not clearly explain lattice energy. An excerpt is:

> "*This is because lattice energy is the energy needed to break 1 mole of an atom into its gaseous ions* (STC059).

For Item 10, the difficulty index was *.33*, with only 32.6% of the students demonstrating full scientific understanding of the concept related to the standard enthalpy of formation of molecular oxygen (O_2). That is, 67.4% of the students had no scientific understanding that the standard enthalpy of formation of molecular oxygen is 0 kJ/mol. Some alternative conceptions and other conceptual difficulties were found from the explanations of the 67.4% of the students who had partial understanding and no scientific understanding of the concept.

Alternative conceptions: Of all the explanations provided to this item, 49.7% were alternative conceptions. For instance, some of the students had the conception that enthalpy of formation is an endothermic process with a positive enthalpy change value. An excerpt is:

> "*Enthalpy of formation involves absorption of heat from the surroundings into the system, hence endothermic which always has positive value*" (STC055).

Also, a diatomic molecule has zero enthalpy of formation. An excerpt is:

> "*This is because the enthalpy of diatomic molecules like* O_2 *is always zero*" (STC095).

All molecules have no enthalpy of formation. An excerpt is:

> "*All molecules have an enthalpy of formation of zero*" (STC140).

Other conceptual difficulties: The composition of explanations that constituted other conceptual difficulties was 17.7%. For instance, some of the students expressed ideas that were not related in any way to standard enthalpy of formation of substances in their most stable forms. An excerpt is:

> "*This is because the standard enthalpy of formation of oxygen is -120.9 and since it is oxygen gas (O_2) it is -241.8 kJ/mol^{-1}*" (STC035).

With a difficulty index of .*25*, Item 11 was very difficult for most of the students to conceptualise that the standard heat of reaction between Zn and Cu^{2+} is 216.8 kJ released per mole. That is, only 24.8% of the students demonstrated full scientific understanding of the concept whereas 75.1% had no scientific understanding of it. Alternative conceptions and other conceptual difficulties were found from the explanations given by the 75.1% of the students who had partial and no scientific understanding of this concept

Alternative conceptions: The proportion of alternative conceptions in the explanations provided to Item 11 was 38.4%. For instance, some of the students had the conceptions that reduction and oxidation reactions account for the enthalpy change of the reaction. An excerpt is:

> "*This is because $Zn_{(s)}$ is undergoing oxidation and the Cu^{2+} is undergoing reduction. The overall reaction is -88.0 kJ/mol which means 88.0 kJ is released per mole*" (STC108).

The reduction half of the reaction needs to be reversed to get a positive standard enthalpy change. An excerpt is:

> "*This is because Zn(s) is undergoing reduction reaction, hence it is reversed to attain a positive ΔH^o. Therefore, the standard heat of the reaction becomes +216.8 kJ absorbed*" (STC127).

An enthalpy of 216.8 kJ per mole was absorbed from the surrounding, making the reaction endothermic contrary to the accurate scientific explanation that the reaction was exothermic. An excerpt is:

> "*...the overall enthalpy change is endothermic which absorbs heat from the surrounding*" (STC113).

Other conceptual difficulties: 36.8% of the explanations provided by the students were conceptual difficulties. For instance, some of the students showed difficulty in calculating for the enthalpy change of the reaction. An excerpt is:

> "*Heat is released for the formation of* Zn^{2+} *while heat is absorbed for the formation of* Cu^{2+}*. Therefore, their* $\Delta H^{o}{}_{f}$ *gives -88 kJ/mol. Hence heat is released for the overall reaction (exothermic)*" (STC115).

On Item 12, the difficulty index was *.50*, meaning it was moderately difficult with 49.6% of the students demonstrating full scientific understanding of the order in which concentrated sulphuric acid should be added to water during a dilution process. That is 50.4% of the students could not conceptualise that the acid should be added to water. There were some alternative conceptions and other conceptual difficulties in the explanations of the students who had partial and no scientific understanding of the concept.

Alternative conceptions: Among the explanations provided, alternative conceptions constituted 7.4%. For instance, some of the students explained that the acid would precipitate in the water. An excerpt is:

> "*... the reaction* H_2SO_4 *is a strong acid and therefore adding it to the water will cause the acid to settle at the bottom of the water*" (STC009).

Other conceptual difficulties: Of the explanations provided by the students to this item, 42.9% were other conceptual difficulties. For example, some of the students used acid-base reactions to explain the reaction between concentrated acid and water. An excerpt is:

> "*Acid-base reactions generate a high amount of heat hence an acid is added to the base*" (STC140).

Also, some of the students knew it to be a precaution in diluting concentrated acids but could not tell the reason behind the precaution. An excerpt is:

> "*One of the precautions during an experiment is adding concentrated acids to water and not vice versa*" (STC007).

Some of the students showed difficulty in explaining the concept by indicating that a fire would be sparked when water is added to concentrated sulphuric acid. An excerpt is:

> "*This is because adding water to an acid will generate heat which will cause fire*" (STC010).

For Item 13, the difficulty index was *.11*, meaning it was very difficult for majority of the students to demonstrate the scientific understanding of heat released when same amounts of sugar are burnt in the body and in a flame. The results indicated that only 10.6% of the students showed full scientific understanding of the concept, whereas 89.3% could not conceptualise that the same amount of heat would be released in both processes. There were some alternative conceptions and other conceptual difficulties found in the explanations of the 89.3% of the students who had partial and no scientific understanding of the concept.

Alternative conceptions: Of the explanations given, 50.4% were alternative conceptions. For instance, some of the students had the conceptions that abundance of oxygen in the atmosphere helps the flame to release more energy than the body. An excerpt is:

> "*There is more oxygen in the atmosphere than in the body and oxygen helps combustion, therefore less heat is released by the body as compared to the flame*" (STC021).

Also, less heat is released by the body as compared to the flame due to the body not requiring heat to break down sugar. An excerpt is:

> "*This is because when the body is breaking down sugar, it does not require heat necessarily*" (STC020).

More heat is released when the sugar is broken down in the body as compared to burning the same amount in a flame because a burning flame is a physical process. An excerpt is:

> "*More heat is released by the body in this process because breakdown of sugar in the body is a complex chemical process while burning in flames is a physical process*" (STC019).

The body uses part of the energy released when some of the sugar is broken down to break down the remaining sugar, releasing less energy than that of the flame. An excerpt is:

> "*The heat released by the body is small as compared to the flame because the breakdown of sugar in the body goes to a process with time, that is, a gradual process so some of the energy is being used to break down the rest whiles in that of the flame, no energy is used by the fire therefore giving out all the energy in the breakdown of the sugar faster and more*" (STC022).

Some of the students had the conception that the breakdown of sugar by the body would not lead to the release of heat. An excerpt is:

> "*Breakdown of sugar (glucose) by the body is not accompanied by heat*" (STC138).

Some of the students also had the conception that the body would release more heat than the flame. This is because sugar breaks down easily in the palm than in the flame. An excerpt is:

> "*This is because when a cube of sugar is squeezed in the body (palm) it is easily broken down as compared to when flame is applied to it*" (STC046).

Other conceptual difficulties: 38.9% of the explanations given to this item by the students were other conceptual difficulties. For example, some of the students had difficulty in conceptualising that both processes were combustion reactions and so, both were exothermic processes. An excerpt is:

> "*This is because there will be an exothermic reaction and therefore heat will be released by the body, whereas in the flame, heat will be absorbed*" (STC032).

Item 14 was very difficult with a difficulty index of *.28*, which indicated that a greater percentage of the students had no scientific understanding of the concept related to the enthalpy changes involving neutralisation reactions. Of the 141 students, only 28.4% demonstrated full scientific understanding, while the remaining 71.6% of the students could not conceptualise that the enthalpy change would be greater for a strong acid and strong base than for a weak acid and strong base. Some alternative conceptions and other conceptual difficulties were identified in the explanations of the students who had partial and no understanding of the concept.

Alternative conceptions: Of all the students' explanations given to this item, 52.7% were alternative conceptions. For instance, some of the students had the conception that all neutralisation reactions have zero enthalpy because the acid is neutralised by the base. An excerpt is:

> "*Neutralisation has value of zero enthalpy so no matter how strong or weak the reaction is, it neutralises and they have same enthalpy*" (STC091).

More energy is needed to complete the reaction between a strong acid and a strong base to achieve neutralisation. An excerpt is:

> "*For a strong acid and a strong base, more energy is required during the neutralisation*" (STC048).

An exothermic reaction is required to completely dissociate a weak acid or base. An excerpt is:

> "*When acid or base is weak, the energy released is smaller. This is because an exothermic reaction is needed to completely ionise the weak acid or base before the actual neutralisation between* H^+ *and* OH^- *ions. It will therefore release smaller energy*" (STC067).

All electrons and reactants are used accounting for the release of a high enthalpy change for the neutralisation reaction between a strong acid and a strong base. An excerpt is:

> "*When a strong acid and a strong base react, all the electrons and reactants are used up and so relatively high amount of heat is released*

> *unlike a weak acid and a strong base where there is a partial use of reactants in the neutralisation process*" (STC086).

Enthalpy change of neutralisation reactions is determined by concentration of the reactants. Hence, strong acid and base will have a greater enthalpy change than for a weak acid and a strong base. An excerpt is:

> "*This is because strong acids and bases are more concentrated than weak acid*" (STC087).

The enthalpy change is greater for a weak acid and a strong base neutralisation than for a strong acid and strong base due to ionisation. An excerpt is:

> "*This is because a strong base dissociates to produce a lot of* OH^- *and a strong acid dissociates to produce plenty* H^+. *These two ions will be neutralised and therefore less heat will be produced and wouldn't affect enthalpy much but for a strong base and a weak acid, the weak acid dissociates partially while the strong base a lot so there will be excess OH- ion which will cause great change in enthalpy*" (STC019).

Other conceptual difficulties: Among the explanations given by the students, other conceptual difficulties constituted 18.9%. For instance, some of the students showed difficulty in explaining the concept of enthalpy change of neutralisation on the basis of Hess's law. An excerpt is:

> "*From Hess' law, enthalpy of reaction is independent of the reaction path*" (STC089).

Also, some of the students had difficulty in conceptualising that there would be a difference between the enthalpy changes of neutralisation for the two separate pairs. An excerpt is:

> "*Because they are all neutralisation reaction, there will be no difference*" (STC097).

On Item 15, the difficulty index was found to be *.31*, showing that the item was difficult for most of the students to get the full scientific understanding of the concept related to the standard enthalpy of combustion of glucose. Of the 141 students, only 30.5%, demonstrated the full scientific understanding of the concept whereas 69.5% could not conceptualise that the standard enthalpy of combustion of glucose was -2.8×10^3 kJ. Among the explanations provided by the 69.5% of the students who had partial and no scientific understanding of the concept, some alternative conceptions and other conceptual difficulties were identified.

Alternative conceptions: The percentage of explanations identified as alternative conceptions was 40.5. For instance, some of the students had the conception that the enthalpy change is positive because energy is absorbed in combustion reactions. An excerpt is:

> "*Because in combustion, energy is absorbed and hence the sign of the* ΔH^o *changes to be positive*" (STC095).

Also, some of the students conceptualised that enthalpy change is the act of burning in the presence of oxygen. An excerpt is:

> "*Enthalpy change means burning a chemical in excess oxygen but in the equation given, oxygen is rather being produced, so the equation is reversed and so is the sign*" (STC023).

Other students conceptualised that the enthalpy change for the reaction was -2.8×10^3 kJ because the reaction was endothermic. An excerpt is:

> "*This is because this reaction is an endothermic reaction for combustion of glucose*" (STC102).

Also, some of the students mentioned that energy was conserved in the combustion of glucose and hence, the enthalpy change remained the same. An excerpt is:

> "*The enthalpy change for combustion is same as the enthalpy change of formation since energy was conserved*" (STC118).

In addition, some of the students stated that oxygen plays no role in combustion of glucose. An excerpt is:

> *"The burning of $C_6H_{12}O_6$ obtains a negative sign with no contribution from the O_2*" (STC005).

Other conceptual difficulties: Of the explanations given, other conceptual difficulties constituted 29.0%. For example, some of the students knew that energy was released but could not show the correct enthalpy change value. An excerpt is:

> "*Energy is been released*" (STC117).

Also, some of the students had difficulty in expressing the role of oxygen in the process. An excerpt is:

> "*Combustion is an exothermic reaction. Oxygen gas in its pure standard state is 0.*" (STC005).

Categories of students' alternative conceptions in thermochemistry

As mentioned earlier, the Research Question One explored the categories of the identified students' alternative conceptions in thermochemistry in line with the NRC (1997) reported categories of alternative conceptions as preconceived notions, non-scientific beliefs, conceptual misunderstandings, vernacular misconceptions, and factual misconceptions. The percentage occurrence of the various categories of alternative conceptions in thermochemistry are presented in Figure 3.

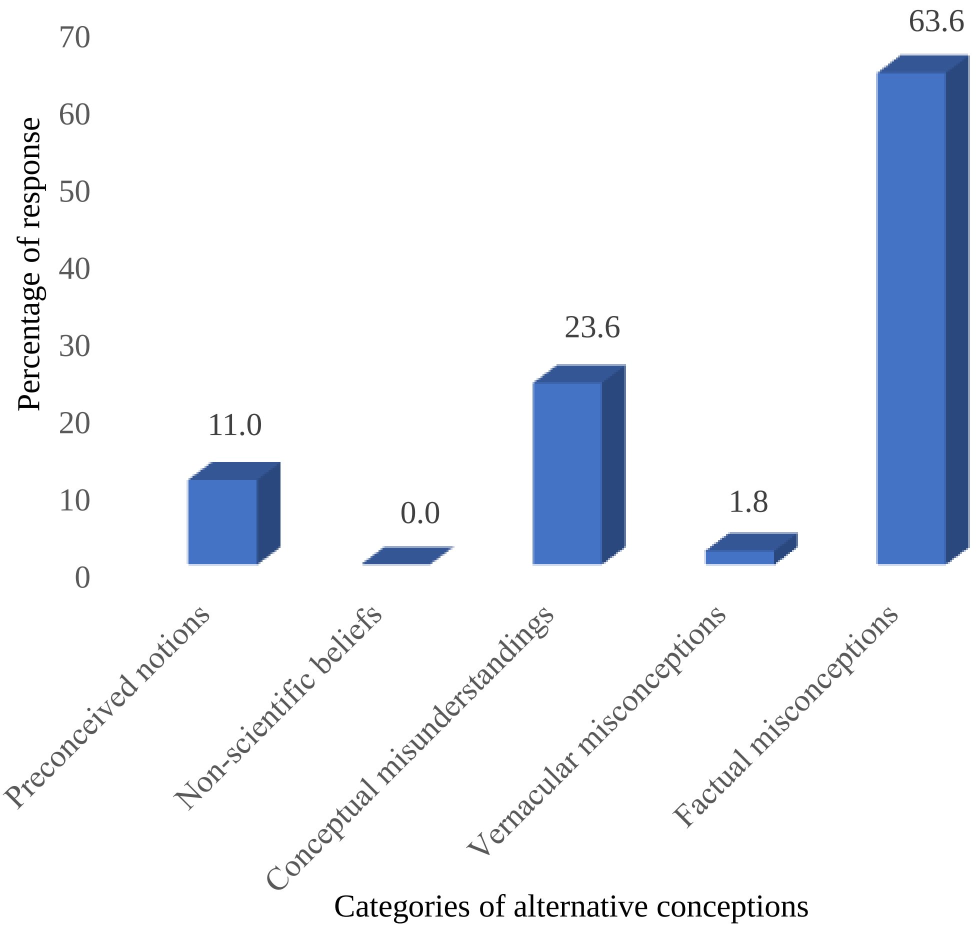


Figure 3: Bar chart of categories of students' alternative conceptions in thermochemistry.

Source: Field data (Ofori-Ahenkan, 2020).

From Figure 3, the results indicated that four out of the five categories of alternative conceptions, which are preconceived notions, conceptual misunderstandings, vernacular misconceptions and factual misconceptions were present among the students' explanations of thermochemistry concepts. The remaining one category, non-scientific beliefs, was absent among the alternative conceptions identified.

Majority (63.6%) of the students' alternative conceptions in thermochemistry existed as factual misconceptions. That is, they were borne on false ideas that were learnt at early ages and remained unchallenged till students learning of thermochemistry. For instance, students might have learnt that gases like H_2, O_2, N_2, F_2, and Cl_2 naturally exist as diatomic molecules with zero enthalpies of formation. Later, in thermochemistry, they might have generalised this idea that all diatomic molecules have zero enthalpy of formation. An excerpt is:

> *"The enthalpy of diatomic molecules like O_2 is always zero, hence the zero enthalpy of formation*" (STC095).

Also, students might have learnt that in the formation of some products, heat is required. This might have made them have the idea that enthalpy of formation was an endothermic process and always had a positive enthalpy change value. An excerpt is:

> "*Enthalpy of formation involves absorption of heat from the surroundings into the system, hence endothermic which always has positive value*" (STC055).

Again, students might have learnt that the application of heat is needed to break down a substance into its constituents. This might have caused the students to conceptualise that water vapour needs to be heated before the molecules can break down to form liquid water. An excerpt is:

> "*When gaseous H_2O is heated the molecules breakdown to form liquid H_2O*" (STC045).

Regarding conceptual misunderstandings, 23.6% of the students' alternative conceptions in thermochemistry were present under this category.

That is, students' conceptions that emanated from the failure of instructions of chemistry (science) lessons in assisting students to confront their earlier preconceived notions and nonscientific beliefs. For instance, students might have learnt that atoms do gain electrons to achieve stability, but had failed to use that knowledge to confront their preconceived notions that extreme volatility of gases at room temperature is different from unstable electronic configuration. An excerpt is:

> "*$Cl_{(g)}$ is in the gaseous state and unstable and therefore has to gain an electron in order to become stable. $Cl_{(g)} \longrightarrow Cl^{-}$ is the process leading to the gain of the electron needed that is the first electron affinity of chlorine*" (STC025).

Again, students might have learnt that when necessary amounts of heat are applied to liquids, they boil and evaporate into gases. However, this knowledge was probably not enough for the students to conceptualise that removal of heat, rather than application of heat is necessary for condensation to occur. An excerpt is:

> "*Condensation is the process by which gaseous substances change to liquid by the application of heat*" (STC004).

Furthermore, 11.0% of the students' alternative conceptions were present as preconceived notions. That is, the students' ideas obtained from daily familiarities. For instance, students knew that the air in the atmosphere consists of some percentage of oxygen together with other gases. They also knew from their daily familiarities that oxygen is needed for combustion to occur. Hence, the students conceptualised that more oxygen in the atmosphere would support the burning of sugar in a flame to produce more heat as compared to lesser oxygen in the human body supporting the burning of same amount of sugar to release lesser amount of heat. An excerpt is:

> "*There is more oxygen in the atmosphere than in the human body and oxygen helps combustion, therefore less heat is released by the body as compared to the flame*" (STC021).

Also, students knew from their daily familiarities that energy is required to apply a force on an object to move it through a distance. Hence, students might have related the transformation of energy to the application of force and used it to explain that energy was used in the form of force, which would cause a physical change in a substance. An excerpt is:

> "*Energy is being used in a form of force and whenever force is applied there will be physical change*" (STC006).

Vernacular misconceptions, which were the inaccurate meanings that students gave to scientific words as a result of how those vocabulary were used in their daily activities on thermochemistry, constituted 1.8% of the alternative conceptions identified. For instance, from the everyday life meaning of the word 'neutral', which suggests neither positive nor negative, students explained that neutralisation reaction would neither have a negative nor positive enthalpy change value, but would be zero as neutral. An excerpt is:

> "*Neutralisation has value of zero enthalpy so no matter how strong or weak the reaction is, it neutralises and they have same enthalpy*" (STC091).

Again, students might have used the violent nature of the reaction when water is added to a concentrated acid and the inaccurate meaning of heat as a measure of hotness coming from the application of fire to literally explain that a fire would be sparked when water is added to a concentrated acid. An excerpt is:

> "*This is because adding water to an acid will generate heat which will cause fire*" (STC010).

From the results presented, students have alternative conceptions and other conceptual difficulties in thermochemistry. The findings from the quantitative aspect (test scores) of the first research question validate the findings from its qualitative aspect (alternative conceptions). This is evidential as the percentage of students who scored the maximum marks on the various items (classified as full understanding) was lower than the percentage that scored partial marks and no marks at all. It could be deduced from this evidence that the presence of alternative conceptions in thermochemistry among the students accounted for the inability of majority of the students to exhibit the full scientific understandings of the various items.

In this study, most of the students' alternative conceptions were related to lack of scientific understanding of endothermic and exothermic processes. For instance, some of the students could not conceptualise that the enthalpy change value of a reaction in which heat is released assumes a negative sign to signify that the reaction is exothermic (Turk & Calik, 2008; Wiji & Mulyani, 2018). Also, students could not clearly differentiate between endothermic reactions and exothermic reactions (Rahmayani, 2017) when thermochemical reactions were presented to them. Moreover, students in this study showed lack of scientific understanding about thermodynamic systems (Dega & Govender, 2016) in that they considered all exothermic reactions as involving the exchange of both heat and mass to the surrounding. This conception of the students undoubtedly points to the fact that they conceive exothermic systems to be synonymous with open systems because there is the exchange of heat with the surrounding in both cases. Therefore, they think that there will be exchange of mass in both as well.

Nevertheless, this is not necessarily the case in exothermic reactions. This is inaccurate as a closed system, in which there is no exchange of mass with the surrounding, can be exothermic. However, it must be said that scientific understanding of endothermic and exothermic processes is very important in learning thermochemistry because every thermochemical reaction is exclusively classified under either of the two (Chen et al., 2017). As a matter of necessity, chemistry educators need to devote quality learning time and adopt cognitive conflicting instructional strategies to underlining the correct conceptual understanding of the types of thermodynamic systems and the classification of thermochemical processes as endothermic or exothermic. It is after understanding these sub-concepts that students understanding of all the other sub-concepts will be made easier.

On enthalpy changes of neutralisation reactions, some students in this study conceptualised and explained that neutralisation reactions absorb heat and hence always have enthalpy change value greater than zero, which is contrary to the scientific point of view that enthalpy changes of neutralisation reactions are always less than zero due to the fact that all neutralisation reactions are exothermic reactions, giving off heat to their surroundings (Chang, 2010). Some of the students also conceptualised that the enthalpy change value would be greater than zero for neutralisation reaction between a strong acid and a strong base and less than zero for a weak acid and a strong base. Furthermore, some of the students possessed some alternative conceptions, such as all neutralisation reactions have zero enthalpies because they conceptualised that the reactants neutralise each other in the process. These explanations by the students are inconsistent with the scientific point of view relating to neutralisation. Not only is this issue seen in the Ghanaian context but elsewhere as students express an idea that the products of neutralisation reactions must be neutral (Taber, 2019). Thus, students lack the accurate understanding of enthalpy change of neutralisation reactions (WAEC, 2018) in that they conceptualise the product of a neutralisation reaction should neither be acidic nor basic but be neutral. This alternative conception might be due to the literal meaning that students give to the word ‘neutral’ in their everyday conversations (Faizal et al., n.d.; Pathare & Pradhan, 2011). Although the language of chemistry may be complex and lead to the development of alternative conceptions among students (Hanson et al., 2011), it is imperative that teachers pay attention to how scientific terms feature in students’ daily conversations and ensure that the literal meanings assigned to terminologies are not applied in chemistry lessons.

In relation to the conversion of energy from one form to another, energy can always be accounted for, although not all energy will be used for meaningful work. This is because energy can neither be created nor destroyed. However, students in this study conceptualised that some of the energy could not be accounted for as it was lost in the process. This explanation might have been inspired by the students’ lack of scientific understanding of wasted energy (energy that is not used for meaningful work). Also, some of the students could not explain conversion of energy in chemical terms, but used unrelated scenario (food chain) in biological terms, which signifies that some students conceptualise energy differently and cannot apply the concept of energy conservation in real life situations (Dega & Govender, 2016). Even though the concept of energy is taught right from basic schools due to its importance and the several applications it has in our daily activities, the finding made in this study gives an indication that the teaching and learning of energy from the lower level to the SHS level is problematic and needs to be well addressed as soon as possible as most of the students' alternative conceptions were false ideas that they learnt from early stages which remained unconfronted till their current stage of learning chemistry.

On the concept of bond formation and bond breakage, the scientific concept is that bond formation is an exothermic process whereas bond breaking is an endothermic process. However, in this study, students conceptualised that bond formation is a process that involves the absorption of heat (endothermic) whereas bond breaking is accompanied by release of heat, making it exothermic (Cooper & Klymkowsky, 2013). This means students visualise chemical bonds as a storage of energy and breaking of bonds as releasing energy (Taber, 2019). Perhaps, the reason students keep holding unto this alternative conception is due to the abstract nature the teaching of chemical bonding has been over the years in most high schools. More so, using an analogy of chemical bonds as holding onto a physical object, it is not out place for students to think that energy is needed to hold onto the object and that same energy is released when no more holding onto the object. In some cases, the analogies and models that are used to teach abstract concepts such as chemical bonding create the alternative conceptions among students (Taber, 2015) as the students may regard those teaching devices as the main concepts the teacher wants to teach. To deal with such alternative conception, appropriate analogies and models need to be used in teaching abstract concepts.

Additionally, some students conceptualised that burning sugar in a flame would yield more energy than breaking down same amount of sugar in the human body. This alternative conception might be based on the idea that higher temperature directly means having higher heat (Saricayir et al., 2016), which makes the flame, having higher temperature, produce greater heat if the sugar is burnt in it as compared to the human body with lower temperature. However, contrary to the students' alternative conceptions, burning sugar in a flame will release same amount of energy as breaking down sugar in the human body so long as the same amount of sugar is involved in both instances and the conditions of the chemical reaction remain the same.

With regards to the calculation of enthalpies of reactions, the finding made was that most of the students had significant conceptual difficulties in that they could not use formulae as well as following right steps in calculating for enthalpy change values when applying the Hess' law of heat summation (Retno et al., 2018; Wiji & Mulyani, 2018). In addition, a section of the students could not apply the stoichiometric amounts of substances in doing calculations on heats of reactions (Hanson, 2020), and some of the students conceptualised that all gases occupy a volume of 22.4L by not considering the stoichiometric amounts of gases in determining the volume they would occupy at STP (Sreenivasulu & Subramaniam, 2013). These calculation difficulties exhibited by the students could be a multidisciplinary problem with mathematical weaknesses being the root causes though the current study did not investigate this further. This necessitates the need for chemistry teachers to emphasise on helping students overcome calculation challenges in chemistry though this may require having to do more with mathematics.

While the NRC (1997) gives five categories of alternative conceptions, this study has shown that in relation to the thermochemistry concept, not all five categories prevail. Categories of students' alternative conceptions identified in thermochemistry are factual misconceptions, conceptual misunderstandings, vernacular misconceptions, and preconceived notions. Unlike in other chemistry concepts where non-scientific beliefs are present among students' alternative conceptions (Hanson, 2020), the non-scientific beliefs category is not present among students' alternative conceptions (Adu-Gyamfi & Ampiah, 2019) as found in this current study and that means the traditional and religious beliefs of chemistry students have negligible or no influence on development of alternative conceptions in the thermochemistry concept. As most students' alternative conceptions were in the factual misconceptions category, it means that a greater proportion of students' alternative conceptions in thermochemistry are as a result of conceptions that are built on false ideas which have not been confronted from early ages till current stage of learning chemistry. Therefore, a lot of probes need to be done by chemistry educators to identify those false ideas, help the students to unlearn them, and present them with the accurate information. This will also demand the investigation of preconceived notions that students have in relation to the thermochemistry concept so that chemistry lessons can target at helping the students confront those conceptions because the conceptual misunderstanding and preconceived notions categories featured as the second and third most occurring categories respectively. There is the need for sensitising students on how chemistry terminologies feature in their daily activities and conversations as the vernacular misconceptions category was also found. Although, vernacular misconceptions appeared least among all the categories identified, it still needs to be given attention as language plays an indispensable role in daily activities and in the learning of chemistry concepts, in which chemistry terminologies will definitely find their way into everyday conversations.

Factors Accounting for Students' Alternative Conceptions

The second research question investigated the factors accounting for students' alternative conceptions. To answer this research question, 12 students were selected and interviewed using IFACT. The results are presented in subsequent paragraphs. From the analysis of the data from the interviews, three factors were identified as accounting for the alternative conceptions of SHS chemistry students in thermochemistry. These three factors are teacher-related factor, textbook-related factor, and daily experiences factor.

Teacher-related factor

The teacher-related factor contributing to alternative conceptions among students is one that the teacher is solely responsible for. For instance, content knowledge of the teacher, knowledge of the teacher about the learners, teaching skills, and evaluation skills. The teacher-related factor is sub-themed as pedagogical skills, content knowledge, and assessment and evaluation skills. The pedagogical skills are concerned with how teachers deliver lessons in the classroom using appropriate instructional strategies, including communication and interaction with students. The content knowledge refers to how well a teacher demonstrates an understanding of the subject matter. Lastly, the assessment and evaluation skills refer to means by which the teacher probes whether the objectives of the lesson have been achieved.

Teachers' pedagogical skills

On the pedagogical skills of the teachers, the focus was on finding out from the students how their teachers convey contents of lessons in ways that they (the students) can understand, remember, and apply. It came out of the responses that the pedagogical practices of the teachers have the likelihood to harbour alternative conceptions among the students. For example, a student (STC077, from School B) had this to say:

> *"…he begins by telling us to open to [a page in a recommended textbook] where we ended our previous lesson and begin from there. He then tries to explain what is written in the textbook to us. We also ask questions on things we don't understand from the book or from his explanation, he gives us answers to our questions. When it gets to some things like calculations or illustrations with diagrams that we don't have in the textbook, he goes to the board and do the calculations or draw the diagram to do the illustration for us. Sometimes too, he calls one of us who can do the calculation to go to the board and do it".*

The interviewer intruded by asking: what then happens to those who do not have copies of the textbook? The student continued by saying that:

> “*Many of us are having copies so he tells the few ones not having it to sit beside some of us having the textbooks and copy the note later from our textbooks.*”

Also, a student (STC052, from School A) had this to say:

> “*When we begin a new topic, the teacher first comes to introduce the topic to us by letting us have some discussions on it. So, we all contribute to the discussion … and we also ask some interesting questions for clarifications. He writes some few things on the board, which is not the actual note he wants to give to us, but just for the sake of clarification. Then he will give us either exercise or assignment to do. At another time when we have a lesson with him, we then write the notes on the previous discussion we had. If we finish writing the notes and there is enough time left, we begin another discussion again and write the notes later.”*

Another student (STC140, from School C) added on how her chemistry teacher teaches by saying that:

> “*Our teacher comes to class and talks about what he is coming to teach us. He always tells us to pay attention to what he is saying and gives us the chance to ask questions getting to the end of the lesson. He talks for some time and then goes to the board to write the notes for us. After that, he will come back to talk about another thing and go back to the board to write again. All that while, we will be quiet and listening to him. When it is getting to about 20 minutes to end the lesson, he will now give us the chance to ask questions. By that time, some of us might have forgotten our questions and so we only try to*

> *remember them. If not, we keep quiet till he leaves. He will then give us exercise before the lesson finally ends*."

These views of students showed that teacher's pedagogies were all about exposition where there were reading of materials to students, writing on the chalk or white board for students to write down into their books, and questioning students' conceptions. Students were seen as passive recipients, only coming in to read from textbook or answer teacher's questions. Also, teacher's pedagogies were exposition as it was not clear scaffolds were provided to help students to learn nor any opportunity provided for students to communicate and share ideas on thermochemistry among themselves leading to meaning making. As if these were not enough, students interviewed added issues relating to knowledge of their teachers in the content that they teach to students.

Teachers' content knowledge

With regard to the content knowledge of teachers, the focus was on finding out from the students their opinions on how knowledgeable their teachers were in the chemistry they taught them. Students expressed several views on teachers' content knowledge in thermochemistry. For example, STC077 mentioned that:

> "*My chemistry teacher uses a textbook all the time. Some other teachers who teach us different subjects come to class with their own notes (that is main ideas) that they have prepared and even some come without any notes at all but they teach for us to understand. Since my chemistry teacher teaches us directly from the textbook, I guess he is not that good at the content*".

This gave an indication that the student was not sure of the teacher's content knowledge on thermochemistry and that whatever was in the textbook was transferred to them without the teacher demonstrating control over the content. Also, a student (STC113, from School C) had this to say about his chemistry teacher:

> "*… he himself tells us to make corrections to some of the things he has taught us already. He is a new teacher who just started teaching us in second year and I think it will take him some time to be very good in the content like our former teacher who taught us in first year*."

However, a student (STC010, from School A) mentioned something contrary to the views expressed by the other students on the weak teacher content knowledge. That is:

> "*My chemistry teacher is very good. When he is teaching, you can tell that he knows what he is saying very well. When I go home and I compare my chemistry notes with the notes of my friends from other schools, I see that my notes contain a lot of information than those of my friends. He hardly makes mistakes in front of the class unless maybe he writes on the board and make some few errors which we draw his attention to and he corrects them immediately*."

It could be seen from the views presented on the teacher content knowledge in thermochemistry that though this knowledge affects conceptual understanding leading to alternative conceptions, students expressed mixed feeling whether their teachers have mastery of thermochemistry. Hence, this current study could not have probed further by involving a large number of students on this, as a limitation of using interviews for collecting data from the students.

Teacher assessment and evaluation skills

On the assessment and evaluation skills, the focus was on finding out from students the ways by which their teachers find out if they have understood what was taught in a class. The responses given by the students suggested that the manner in which teachers conduct evaluation and assessment of their lessons contribute to they (students) retaining their alternative conceptions. For instance, a student (STC098, from School B) had this to say:

> "*… our exercise books are with our teacher. As of now, we do not know if the answers we wrote for the exercises he gave us are correct or not. We can write about five exercises before he even scores one of them. So always it becomes difficult for us to even write our corrections.*"

Another student, (STC140, from School C) also said in relation to her teacher's assessment of lessons that:

> "*Even a lot of the exercises and assignments we have done have not been scored and brought back to us so we don't know whether we have got them correct or wrong.*"

In addition, a student (STC115, from School C) mentioned that:

> "*Our teacher always complains that we the students are many so it is not easy for her to score our exercises and assignments. Due to that, she does not regularly give us work to do. Even if she will give us any work to do, she doesn't make the questions plenty.*"

These are indicative of the fact that feedback practices of teachers teaching thermochemistry are poor and that students hardly see their weaknesses, such as alternative conceptions to work at eliminating them. Also, teachers go to the next lesson on thermochemistry without knowing the alternative conceptions students had in previous lessons which could compete with their scientific understanding in thermochemistry.

Textbook-related Factor

The textbook related factors are features of textbooks that contribute to alternative conceptions among learners who read the textbooks. The textbook-related factor is sub-themed as clarity of concepts, incomprehensible terminologies, and abridged calculations. The clarity of concepts is the clear and self-explanatory manner in which the content is presented. Incomprehensible terminologies are thermochemistry vocabulary used in textbooks that learners have difficulty in understanding. Lastly, abridged calculations are the calculations presented in textbooks in which some or most of the steps were skipped before presenting the final answer.

Clarity of concepts

With regard to the clarity of concepts, the focus was on finding out whether the thermochemistry content in the textbooks that the students used was presented clearly enough so that they could easily read on their own, understand, remember and apply. The responses obtained suggested that how thermochemistry content was presented in some textbooks made them lack clarity. For instance, a student (STC010) asserted that:

> "… *In the textbook, there are certain words I don't understand. Some explanations contain so many words and I get confused after reading. Let me say some of the explanations in the textbook are not clear. But looking at my teacher's note, the explanations are not lengthy and they*

> *are not few either. So, it is in-between and I understand that better than the textbook. But when I am learning, I always make use of the two so that if one doesn't help, the other will help*."

Also, a student (STC067, from School B) mentioned that:

> "*… Sometimes, I have to do a follow-up to my chemistry teacher on some of the things I learn on my own from the textbook so that he can explain them further to my understanding. But for the teachers notes, I don't have a problem understanding them…*"

Another student (STC048, from School A) mentioned that:

> "*The things in my textbook are not detailed as the notes my chemistry teacher gives us. So, I always use my chemistry notes as a supporting material to give me clearer understanding when what I have in the textbook is not enough for me*."

The results indicated that students had varied reactions towards the clear nature of thermochemistry content presented in some textbooks. This is suggestive that thermochemistry content in some textbooks is either scanty or lengthy and imprecise. Therefore, the content lacks clarity and students cannot easily understand them when reading on their own. On the other hand, students consider their teachers' note on thermochemistry to be clearer for them than the content in the textbooks. This means that the use of the textbooks alone without complements from teachers pose some challenges to students' understanding of the thermochemistry concept.

Incomprehensible terminologies

This relates to thermochemistry terminologies used in textbooks which are not easily understood by students. The purpose was to find out whether students had proper understanding of the terminologies they came across in textbooks on thermochemistry. Relating to this, a student (STC009, from School A) had this to say:

> "*The notes our teacher gives us is equally good as the textbook. But my only problem with the textbook is that some of the words … that are used to explain things are not that easy to understand …*"

In addition, a student (STC098, from school B) said that:

> "*Sometimes when I am reading my textbook, I come across big words that I do not understand unless I refer to a dictionary for their meanings. But that sometimes becomes a problem because I may not have a dictionary at that moment.*"

Also, a student (STC052, from School A) said in relation to the incomprehensible terminologies in textbooks that:

> "*… I must say that some of the words in the textbook are not easy to understand but there are other words too that are easy to understand. So, it is kind of mixed.*"

The results point out that some terminologies used in some textbooks in relation to thermochemistry are beyond the students' understanding with respect to reading assignment. In this case, some of the students are of the view that some terminologies used in some textbooks are not easily understood. Students may then assign different meanings to them which may not represent the true meaning in thermochemistry, leading to the acquisition of alternative conceptions in the minds of the students.

Abridged calculations

As some of the students showed deficiencies in performing calculations in relation to thermochemistry, the study probed why they had such difficulties during the interviews. The results suggest that some textbooks patronised by students do not present calculations in a step-by-step approach. For instance, a student (STC100, from School B) had this to say:

> "*In terms of calculations, the teacher's note is better as compared to the textbook. The calculations in the teacher's note are very detailed with a step-by-step approach. So, it is very easy to understand the calculations. But for the textbook, they jump some of the steps and you get confused along the line because you don't know how certain figures are obtained. All you see is that they appear in the calculations. Some even skip a lot of steps and present the final answer*."

In addition, a student (STC129, from School C) said that:

> "*I find the calculations we do with our teacher to be more understandable than some of the calculations I see in the textbook. Some of the textbook calculations have some of the steps removed to make them short and that does not help.*"

A student (STC048, from School A) said, in relation to abridged calculations in some textbooks, that:

> "*… some of the steps of some calculations in the textbook are omitted. So, it becomes difficult to understand the calculations very well.*"

The result was indicative of the fact that some textbooks do not present calculations in a methodical way that students can follow and understand on their own. Students relying on the use of textbooks in which calculation steps are omitted can obviously have difficulties in performing similar calculations. However, the result acknowledged the clarity and orderliness of presentation of calculations in the presentations given by their teachers, suggesting that teacher's presentations help students understand calculations on thermochemistry better compared to textbooks.

Daily experiences

The daily experiences are knowledge gained by students outside formal instructions, which form part of their cognition. In this study, the interviews conducted with the students suggested that students' alternative conceptions can partly be attributed to their daily experiences as some students confirmed the application of their daily experiences in explaining concepts in the classroom. With regard to this, a student (STC010) had this to say:

> *"I bring my knowledge from my own experiences to the classroom. There are a lot of things happening around us in our environment already that we later come to learn about in the classroom. So, when learning in the classroom, I try to use what I already know from experiences through observation to explain some of the things we are learning especially when I realise that they have something in common."*

In relation to the application of knowledge from daily experiences to classroom lessons, a student (STC052) also said that:

> *"I sometimes apply what I learn from my surroundings and the things I do at home to my classroom lessons and sometimes too I apply what I learnt in class to do some things at home. I do that because our teachers tell us to apply our knowledge in solving problems."*

Another student (STC098) also had this to say:

> "*Some of the things we come to learn in the classroom, we have some fair knowledge about them already due to things happening around us. So, in those situations, I try to relate what I know already from outside the classroom to the lesson that we are learning in class.*"

The results from the interview suggested that learners observe whatever happens around them on daily basis, make meaning out of them and apply such meanings to explain thermochemistry concepts in the formal instructional setting. The meaning they construct from what they observe can either be appropriate or otherwise, when compared to the scientific concept. In the event that cognitions students have from their experiences are not in full conformity to the scientific point of view, such knowledge can conflict the scientific concept taught to them, leading to alternative conceptions.

With regards to the sources of alternative conceptions, it was discovered in this study that teacher-related factors, textbook-related factors, and daily experiences factor were the main factors reported to account for the students' alternative conceptions. On the teacher-related factors, it came out that teachers' pedagogical skills (instruction presentation styles), were reported not to be of good practice (Hanson, 2020). The study made the finding that some of the chemistry teachers' pedagogies were all about exposition of textbook content to students, in which case some teachers used textbooks as direct substitutes for the content they were to teach. This practice defeats the objectives of the chemistry curriculum as students are encouraged to brainstorm and to engage in discussions to come out with meanings on concepts. Making of meanings of concepts by students should be achieved through participatory teaching approaches (MoE, 2010). More seriously, through the inappropriate instructional presentation style of reading out textbook content to students, the students wholly consume the content of the textbook based on trust (Mondal & Chakraborty, 2013) reposed in the textbook by the teacher even when there are alternative conceptions in the book. Such modes of lesson delivery have greater lapses that give only a narrow opportunity to identify and address students' alternative conceptions. This does not help in addressing students' alternative conceptions and so, chemistry teachers should adopt participatory teaching and learning approaches (Adu-Gyamfi, Ampiah, & Agyei, 2020) for effective teaching and learning of thermochemistry.

The content knowledge of some teachers in thermochemistry is another aspect reported to contribute to students' alternative conceptions. The finding of this study is that some teachers lack mastery and control of the content (Vorsah & Adu-Gyamfi, 2021) on thermochemistry, whereas others do not in the perspective of the students. Though the current study did not investigate further this teacher content knowledge in thermochemistry, it will not be out place to infer that some teachers themselves have alternative conceptions (Koc & Yager, 2016) in thermochemistry. This is due to the fact that studies conducted in Ghana recently have reported on teachers' alternative conceptions in organic chemistry and functional group detection (Adu-Gyamfi & Asaki, 2022; Anim-Eduful & Adu-Gyamfi, 2021). Therefore, teachers with alternative conceptions in thermochemistry may not be able to explain the concepts explicitly for the students to scientifically understand them.

In addition, some teachers were reported not to be evaluating the learning of their students and in some instances, giving late feedback on assessment of students’ learning. However, it must be said that evaluation of students’ learning and giving prompt feedback to students after assessing their learning are important things that teachers must do very often. In the case where evaluation of learning is not done, it becomes impossible to know the knowledge of students juxtaposed with the objectives of instructions given (Barkley & Major, 2015). Teachers must develop the habit of frequently letting the students know what their learning challenges are, and correcting them subsequently (Field et al., 2018) through the use of evaluation and assessment strategies as the late assessment and delayed feedback on students’ responses given through the assessment process can cause inability to deal with students’ learning difficulties (McClain et al., 2018). Moreover, prompt feedback on students’ assessment helps teachers to identify students’ alternative conceptions. When students’ alternative conceptions in chemistry (for example, thermochemistry) are known, it helps in effective teaching because Adu-Gyamfi et al. (2020) advocate for the use of instructional approaches that first identify the alternative conceptions and addressing them thereafter to help students overcome the alternative conceptions, giving way to scientific understanding of chemistry.

With regard to textbooks as source of alternative conceptions, the results point to features of textbooks such as lack of clarity on concepts (Gegios et al., 2017; Vorsah & Adu-Gyamfi, 2021), students coming across incomprehensible terminologies in textbooks (Quílez, 2019; Thonney, 2016), and abridged forms of calculations presented in textbooks as obstructions to their understanding of thermochemistry. One major source of students' knowledge apart from the teacher is textbooks. In reading textbooks, students come across terminologies and concepts that are new to them (Quílez, 2019). If the concepts in textbooks are not well-presented devoid of errors and non-clarity, students will learn without getting the scientific concepts and hence create alternative conceptions in them. Therefore, textbooks need to be well-composed to avoid errors and vagueness that will contribute to alternative conceptions.

In this current study, the results also indicated that students applied their experiences from their environments to explain thermochemistry-related concepts in the classroom (Franke et al., 2013). This is indicative of the fact that students like to transfer and apply knowledge from their own experiences into learning thermochemistry. Although daily experiences of students can have relations with the concepts they learn in the classroom, the veracity, understanding and explanations students may give to those experiences may not be in line with the full scientific point of view. Hence, when explanations given to daily experiences are brought into the classroom setting to explain scientific concepts, it ends up creating alternative conceptions (Capps et al., 2013). This could be the reason behind some of the students' alternative conceptions in thermochemistry that were vernacular misconceptions and preconceived notions.

Relationship between Students Achievement in Prerequisite Concepts and Achievement in Thermochemistry

The third research question sought to examine the relationship between the achievement of the students in the prerequisite concepts and their achievement in the thermochemistry concept. This research question was looked at in four segments as; analysis of performance obtained by the students on TPRC, identification of alternative conceptions in the prerequisite concepts, categorisation of alternative conceptions in the prerequisite concepts, and establishment of the relationship between achievements in prerequisite concepts and thermochemistry.

Students' difficulties and alternative conceptions in prerequisite concepts

The students' response on the TPRC were analysed to find their alternative conceptions and their conceptual difficulties. The understanding of students in the prerequisite concepts are presented in Table 3.

Table 3: Students' Understanding of the Prerequisite Concepts (N = 141)

Item	Full Understanding		Partial Understanding		No Understanding		Difficulty Index
	N	%	N	%	N	%	
1	87	61.7	47	33.3	7	5.0	.62
2	79	56.0	48	34.0	14	10.0	.56
3	73	51.8	27	19.1	41	29.1	.52
4	46	32.6	53	37.6	42	29.8	.33
5	55	39.0	16	11.3	70	49.6	.39
6	10	7.1	0	0.0	131	92.9	.07
7	111	78.7	27	19.1	3	2.1	.79
8	16	11.3	41	29.1	84	59.6	.11
9	29	20.6	25	17.7	87	61.7	.21
10	56	39.7	35	24.8	50	35.5	.40
11	41	29.1	77	54.6	23	16.3	.29
12	81	57.4	49	34.8	11	7.8	.57
13	91	64.5	43	30.5	7	5.0	.65
14	46	32.6	36	25.5	59	41.8	.33

Source: Field data (Ofori-Ahenkan, 2020).

On Item 1, the results showed that students had less conceptual difficulties on the number of valence electrons in group IIA and VA elements. The item difficulty index was found to be *.62*, indicating that 61.7% of the 141 students had full scientific understanding of the concept, whereas 38.3% did not have the scientific understanding that the number of valence electrons present in groups IIA and VA are 2 and 5 respectively. Some alternative conceptions and other conceptual difficulties were found among the explanations of the 38.3% of the students who had partial and no scientific understanding of the concept.

Alternative conceptions: Among the explanations given to this item, 24.6% of them were alternative conceptions. For instance, some of the students had the conceptions that atoms need to release some of their electrons to become stable. An excerpt is:

> "*Group 2 (IIA) members are characterised by only two electrons in their outermost shell. VA elements are also having 5 electrons in their outermost shell hence they need to release some of the electrons to be stable*" (STC001).

A group of elements has electronic configuration equivalent to the number of valence electrons. An excerpt is:

> "*This is because IIA has 2 electrons in the outermost shell and has electronic configuration of 2 and group VA elements have electronic configuration of 2, 5. VA also has 5 electrons in its outermost shell and has electronic configuration of 2, 5*" (STC056).

Other conceptual difficulties: Of all the explanations given by the students to this item in the prerequisite concepts, 13.7% were conceptual difficulties. For instance, some of the students had difficulty in giving explanation for their answers by making reference to incomplete outermost shells. An excerpt is:

> "*Because they don't have fully filled valence orbitals*" (STC014).

On Item 2, the results showed that students had moderate alternative conceptions and other conceptual difficulties on the number of valence electrons that all elements of the same group will have. The item difficulty index was found to be *.56*, indicating that 56.0% of the 141 students showed full scientific understanding of the concept, whereas 44.0% had no scientific understanding that elements belonging to the same group have the same number of valence electrons.

Alternative conceptions: The explanations that constituted alternative conceptions were 35.1%. For instance, some of the students had the conception that moving down the group, electrons fill the same orbital. An excerpt is:

> "*Elements in the same group have the same number of valence electrons because down the group, electrons enter the same orbital*" (STC129).

Also, all elements belonging to a group have the same number of electrons. An excerpt is:

> "*For elements to be in the same group, they have to get the same number of electrons irrespective of the number of shells*" (STC081).

Other conceptual difficulties: Of all the explanations given, 8.9% were other conceptual difficulties, where students found it difficult to explain the concept. For instance, some of the students had conceptual difficulty with understanding the number of valence electrons elements within the same group accept from an atom of another element. An excerpt is:

> "… *because they have formed stable element by accepting one proton*" (STC120).

On Item 3, the results indicated that students had alternative conceptions and conceptual difficulties on the concept of intermolecular forces because the item had a moderate difficulty index of *.52*, meaning 51.8% of the

141 students showed full scientific understanding of the concept while 48.2% had no scientific understanding that the major intermolecular force in I_2 is a covalent bond.

Alternative conceptions: Among all the explanations provided on this item, 39.7% were alternative conceptions. For instance, some of the students had the conceptions that molecular iodine (I_2) has ionic bonds. An excerpt is:

> "*I_2 exist as a crystal in nature. Ionic bonds are responsible for the crystalline nature of I_2*" (STC082).

In covalent bonding, there is sharing of atoms. An excerpt is:

> "*The major intermolecular force in I_2 is covalent bond because there will be sharing of atoms between both elements in order to achieve stability*" (STC087).

Other conceptual difficulties: Of all the explanations given, 8.5% were other conceptual difficulties. For instance, some of the students showed difficulty in explaining covalent bonding. An excerpt is:

> "*There is strong intermolecular bond between the atoms of the elements combined*" (STC094).

Relating to Item 4, the results showed that the students had conceptual difficulties with the concept of hydrogen bonding. The item difficulty index was found to be *.33*, signifying that 32.6% out of the 141 students demonstrated full scientific understanding that CH_3NH_2 was the molecule whose intermolecular forces were hydrogen bonds among the given compounds, while 67.4% of the students demonstrated no scientific understanding of the concept. Some alternative conceptions and other conceptual difficulties were found in the explanations of the 67.4% of the students who demonstrated partial and no scientific understanding of the concept.

Alternative conceptions: Of all the explanations given by the students on this item, 49.8% were identified as alternative conceptions. For instance, some of the students explained that hydrogen bonding occurs between a hydrogen atom and either metals or gases. An excerpt is:

> "*Hydrogen bonding is a type of bond which occurs between metals or gases and hydrogen and it involves the sharing of electrons between the two atoms or elements involved, thus rendering both atoms stable*" (STC116).

Hydrogen bonding takes place in only inorganic compounds. An excerpt is:

> "*Hydrogen bonds occur only in inorganic compounds*" (STC106).

Also, hydrogen atoms are shared in hydrogen bonding. An excerpt is:

> "*The compound that can have hydrogen bonding between its molecules is* CH_3NH_2 *because they can share their hydrogen atoms in bond formations*" (STC107).

Compounds with more hydrogen atoms contain hydrogen bonds. An excerpt is:

> "AsH_3 *and* CH_3NH_2 *are the molecules with hydrogen bonding because these contain more of hydrogen atoms*" (STC121).

The CH_4 molecule has its intermolecular force to be hydrogen bond because it is highly electronegative. An excerpt is:

> "*…* CH_4 *has high electronegativity enough to form a hydrogen bond*" (STC025).

Other conceptual difficulties: Among all the explanations given, 17.6% were identified as other conceptual difficulties. For instance, some of the students showed difficulty with the explanation of hydrogen bonding. An excerpt is:

> "*C forms four bonds to become stable with hydrogen (four bond), As forms 3 bonds to become stable with hydrogen (3 bonds) and Te also forms two bonds with hydrogen to become stable (2 bonds)*" (STC128).

On Item 5, the results showed that students had conceptual difficulties on the concept of hybridisation. The item difficulty index was *.39*, indicating that 39.0% of the students showed full scientific understanding of the concept, whereas 60.9% could not demonstrate the scientific understanding that the specie which did not contain sp^3-hybridised atom among the options given to the item was BH_3. Some alternative conceptions and other conceptual difficulties were identified from the explanations given by the proportions of students who showed partial understanding and no scientific understanding of the concept.

Alternative conceptions: Of all the explanations given, 45.2% were identified as alternative conceptions. For instance, some of the students explained that ammonium (NH_4^+) has 1s and 4p orbitals. An excerpt is:

> "*NH_4^+ does not contain a sp^3-hybridised orbital because it has 1s orbital and 4p orbitals*" (STC129).

Also, the excited state electronic configuration of nitrogen has only one electron in the 2p sublevel. An excerpt is:

> "*NH_3 does not contain a sp^3-hybridised orbital, this is because in its excited state only the $2p_y$ orbital is filled with one electron leaving the $2p_z$ with none*" (STC065).

The BH_4^- specie had gained an extra electron, making it able to bond with five molecules. An excerpt is:

> "BH_4^- *does not contain an sp*^{3}*-hybridised atom because it has gained an electron which makes it to have 5 molecules of hydrogen.* BH_3, NH_3, NH_4^+ *contain 3 molecules of hydrogen*" (STC091).

Other conceptual difficulties: Among all the explanations given, 15.7% were other conceptual difficulties. For instance, some of the students had difficulty with conceptualising sp^3 hybridisation by giving explanations that were not related to hybridisation. An excerpt is:

> "*This is because the specie* (BH_4^-) *has a negative of four electrons so this four will be subtracted from the hybridisation and thus the positive ones left will not be up to sp*^{3}" (STC095).

On Item 6, the results showed that the students had conceptual difficulties with the boiling points of molecules. The item difficulty was *.07*, which indicated that only 7.1% of the 141 students showed full scientific understanding of the concept, whereas 92.9% could not demonstrate the full scientific understanding that HCl would have the lowest boiling point among the list of hydrogen halides provided in the item. Some alternative conceptions were found among the explanations of the 92.9% of the students who had partial and no scientific understanding of the concept.

Alternative conceptions: Some students explained that covalency and boiling point increase down the group. An excerpt is:

> "*Down the group, covalency increases whilst boiling point increases*" (STC007).

HBr has the lowest boiling point due to the large size of bromine. An excerpt is:

> "*This is because HBr has the highest atomic size and thus less energy will be required to break its bonds*" (STC009).

Also, some of the students had the conception that HBr has a lower boiling point than HCl due to bromine having a bigger atomic size than chlorine. An excerpt is:

> "*HBr will have the lowest boiling point at 1atm since the bond between hydrogen and bromine is weaker than all other compounds in the answers provided above. This is so because the atom of bromine is bigger than that of Cl, F and hence they form stronger bonds to hydrogen than Br*" (STC011).

On Item 7, the results indicated that students had conceptual difficulties with atoms that have their K and L shells fully filled. The item difficulty index was found to be *.79*, which indicated that it was quite easy for most of the students to get the full scientific understanding. Out of the 141 students, only 21.3% had partial or no scientific understanding of the concept that among the options provided, the atomic number of the element in whose atom the K and L shells are full is 10. Among the explanations of the 21.3% of the students who had partial and no scientific understanding of the concept, some alternative conceptions were found.

Alternative conceptions: Some of the students explained that both the first and second energy levels have a maximum of 8 electrons each. An excerpt is:

> "*K contains 8 electrons and L contains 8 electrons*" (STC103).

Also, the K and L shells contain atoms. An excerpt is:

> "*This is because the K shell contains 2 atoms of the atomic number of the element and L shell contains 8 atoms of the atomic number of the element which sum up to 10*" (STC032).

With regards to Item 8, the results showed that the students had some alternative conceptions in the concept of boiling point. The item difficulty was *.11*, meaning it was very difficult for most of the students to conceptualise that CO_2 had the highest boiling point among all the molecules listed in Item 8. Of the 141 students, only 11.3% demonstrated full scientific understanding of the concept, while 89.7% had no scientific understanding of it.

Alternative conceptions: Some of the students explained that nitrogen monoxide (NO) contains a hydrogen bond. An excerpt is:

> "*It has a strong hydrogen bond. The stronger the hydrogen bond, the higher the boiling point*" (STC106).

Also, CO_2 has the highest boiling point due to lattice energy. An excerpt is:

> "*CO_2 … has a very high lattice energy*" (STC086).

Nitrogen monoxide is a liquid. Hence, it will have the highest boiling point. An excerpt is:

> "*Only liquids have highest boiling point. CO_2, N_2 and O_2 are gases. So, therefore, NO is a liquid and will have highest boiling point*" (STC121).

On Item 9, the results showed that most of the students had conceptual difficulties on the number of sigma and pi-bonds in ethene. The difficulty index of the item was found to be *.21*, indicating that only 20.6% of the 141 students exhibited full scientific understanding of the concept, while 79.4% could not exhibit the full scientific understanding that ethene has five sigma-bonds and one pi-bond. Some alternative conceptions and other conceptual difficulties were identified from the explanations of the students who showed partial and no understanding of the concept.

Alternative conceptions: The percentage of alternative conceptions among the explanations given by the students was 40.8%. For instance, some of the students explained that C-H single bonds are pi-bonds and H-C bonds are sigma bonds. An excerpt is:

> "*The bond between C and H is pi-bond while sigma bond exists between H and C. Hence,* C_2H_4 *will have 2 pi-bonds and 5 sigma bonds*" (STC114).

Sigma bonds are determined by the number of hydrogen atoms and pi-bonds are determined by the number of carbon atoms present in a compound. An excerpt is:

> "*Sigma and pi bonds are formed by hydrogen and carbon atom respectively. The number of hydrogens determines sigma bond and the number of carbons determines pi-bond*" (STC120).

Also, the pair of bonds that constitute a double bond are all pi-bonds and all single bonds are sigma-bonds, hence ethene has 2 pi-bonds and 4 sigma-bonds. An excerpt is:

> "*There are 4 sigma-bonds and 2 pi-bonds in* C_2H_4 *because the two carbon atoms form double bonds with each other and each forms two single bonds with the four hydrogen atoms*" (STC003).

The electronic configurations of carbon and hydrogen account for four sigma-bonds and two pi-bonds in ethene. An excerpt is:

> "$_6C = 1s^2, 2s^2, 2p^2$; $H = 1s^1$; *hence the 4 sigma bonds occur between the* $2s^2$ *and* $2p^2$, $2+2 = 4$. *The pi-bond occurs between the* $1s^2$ *and* $1s^1 = 1+1 = 2$" (STC001).

Other conceptual difficulties: Of all the explanations given by the students on this item, 38.6% were other conceptual difficulties. For example, some of the students had difficulty in determining the number of sigma and pi bonds by the inability to recognise all the C-H single bonds, but focusing only on the double bond between the two carbon atoms (C=C) in ethene. An excerpt is:

> "*Because* C_2H_4 *is an alkene which has a structure C=C, hence has 1 sigma bond and 1 pi-bond*" (STC100).

The results on Item 10 showed that students had conceptual difficulties with the concept of bonding and non-bonding electron pairs. The difficulty index was *.40*, meaning that it was quite difficult for most of the students to get the full scientific understanding of it. Of the 141 students, 60.3% could not exhibit the scientific understanding that there are 3 bonding and 0 non-bonding electron pairs in boron in the BF_3 molecule. Among the explanations given by the 60.3% of the students who had partial and no scientific understanding of the concept, some alternative conceptions were found.

Alternative conceptions: Of all the explanations given to the item, 60.3% were identified as alternative conceptions. For instance, some of the students explained that boron in BF_3 molecule has 3 bonding and 1 non-bonding pairs of electrons. An excerpt is:

> "*In the* BF_3 *molecule, both elements offer 3 electrons to be shared which gives 3 bonding pairs. B element as the central atom is left with*

> *2 electrons which don't take part in the bonding. They constitute 1 non-bonding pair*" (STC005).

Boron, in the BF_3 compound, needs eight electrons to be stable and since it has three bonding pairs used in forming bonds with three fluorine atoms, it must have a lone pair of electrons to make eight electrons around boron. An excerpt is:

> "*This is because, boron to be stable, needs 8 electrons in the outer shell and fluorine needs only 1 electron. In this case, boron is bonding to three pairs of fluorine electrons, hence boron seems to have a pair of non-bonding electrons*" (STC080).

Also, boron has three bonding pairs of electrons and fluorine has zero non-bonding pair. An excerpt is:

> "*This is because* BF_3 *has 3 bonding electron pairs of B and 0 non-bonding electron pair of the* F_3" (STC032).

Some of the students also conceptualised that boron loses three electrons to achieve stability whereas fluorine accepts the three electrons to become stable, depicting BF_3 as an ionic compound. An excerpt is:

> "*The valency of Boron is +3, meaning it gives off three electrons to become stable whilst fluorine receives 3 electrons to become stable, so they both bond together with boron giving off 3 electrons, not sharing 3 electrons*" (STC021).

On Item 11, the results indicated that there were some alternative conceptions among the explanations given by the students on the molecular geometry of ammonia. The item difficulty index was *.29* indicating that only 29.1% of the 141 students exhibited full scientific understanding, whereas the remaining 70.9% had no scientific understanding that the molecular geometry of NH_3 is trigonal pyramidal.

Alternative conceptions: Of all the explanations given, alternative conceptions constituted 70.9%. For instance, some of the students held the view that all sp^3 hybridised molecules have trigonal pyramidal shape. An excerpt is:

> "*NH_3 has sp^3 hybrid orbitals and sp^3 hybrid orbitals have trigonal pyramidal shape*" (STC109).

In ammonia (NH_3), N has two lone pairs of electrons. An excerpt is:

> "*The N atom has two lone pairs of electrons which repel each other as well as the electrons on the H atom. This reduces the bond angle*" (STC114).

Ammonia (NH_3) has 'sd^3' hybridisation. An excerpt is:

> "*This is because it is made up of one s-orbital and 3 d-orbitals of different energies*" (STC115).

The NH_3 molecule is sp-hybridised with a linear shape. An excerpt is:

> "*The NH_3 molecule has a linear shape because the NH_3 molecule forms the sp orbital and sp orbital is linear shape*" (STC120).

Also, the NH_3 molecule has a trigonal pyramidal shape with a bond angle of 147°. An excerpt is:

> "*NH_3 has trigonal pyramidal shape because it has an angle of 147^o when bonded*" (STC102).

On Item 12, the results indicated that some of the students could not conceptualise the number of electrons in the first energy level of an atom. The difficulty index was *.57*, meaning that it was moderately difficult for the students. Of the 141 students, 57.4% of them showed full scientific understanding of the concept, while 42.6% could not conceptualise that the maximum number of electrons the first energy level can take is two. There were some alternative conceptions in the explanations of the 42.6% of the students who had partial and no scientific understanding of the concept.

Alternative conceptions: Among all the explanations provided to this item, 42.6% were alternative conceptions. For instance, some of the students explained that every energy level must have a maximum of two electrons. An excerpt is:

> "*The main energy level that can hold only two electrons is 1st level because the total number of electrons that must fill any energy level must be two*" (STC124).

Also, based on the octet rule, the maximum number of electrons the first energy level can hold is two. An excerpt is:

> "*According to the octet rule, the first shell i.e., K shell can accommodate only two electrons for which the K shell is the first energy level*" (STC061).

Item 13 had a difficulty index of *.65*, meaning that it was less difficult for the students to conceptualise that when a liquid turns into the gaseous phase, the particles experience a negligible cohesive force, and hence break away. This showed that 64.5% of the students demonstrated the full scientific understanding of the concept, while 40.5% could not demonstrate the full scientific understanding of the concept. Some alternative conceptions were identified in the explanations given by the 40.5% of the students who could not demonstrate the full scientific understanding of the concept. The alternative conceptions constituted 8.4%, while the remaining 32.1% did not provide any explanation to the item.

Alternative conception: Some of the students could conceptualise that force of cohesion is stronger in solids than in liquids but could not relate that to why the particles break away when a liquid becomes a gas. An excerpt is:

> "*When a liquid becomes a gas, the particles break away. This is because the force of attraction between liquid particles are less strong than that of solid particles*" (STC089).

On Item 14, the results indicated that students had conceptual difficulties on the meaning of electronegativity. The difficulty index of the item was *.33*, indicating that the item was quite difficult because only 32.6% of the 141 students exhibited full scientific understanding of the concept, while 67.3% could not exhibit the scientific understanding of it. Some alternative conceptions and other conceptual difficulties were identified in the explanations of the 67.3% of the students who had partial and no scientific understanding of the concept.

Alternative conceptions: Of all the explanations, alternative conceptions constituted 56.6%. For instance, some of the students explained that electronegative atoms pull electrons from the valence shells of electropositive atoms. An excerpt is:

> "*Electronegativity occurs when a more electronegative atom pulls an electron from the outermost shell of another more electropositive atom to itself ...*" (STC090).

The nucleus of an electronegative atom pulls electrons of another atom to itself. An excerpt is:

> "*Electronegativity is the ability of a nucleus of an atom to pull electrons of another atom towards itself*" (STC028).

Also, difference in electronegativity makes electrons move to electropositive atoms. An excerpt is:

> *The difference in electronegativity causes electrons to move to the more electropositive atom*" (STC073).

Other conceptual difficulties: Among the explanations given, 10.7% were other conceptual difficulties. For instance, some of the students had difficulty in conceptualising the concept of electronegativity. An excerpt is:

> "*The bond between the protons and electrons creates a shielding effect making it difficult to eject an electron from the atom*" (STC102).

Categories of students' alternative conceptions in prerequisite concepts

As stated earlier, the Research Question Three sought to find the relationship between students' achievement in prerequisite concepts and their achievement in thermochemistry. This required the identification of the students' alternative conceptions in the prerequisite concepts from the explanations provided in the TPRC. Thereafter, the identified alternative conceptions were categorised in line with the NRC (1997) categories of alternative conceptions as preconceived notions, non-scientific beliefs, conceptual misunderstandings, vernacular misconceptions, and factual misconceptions. The percentage occurrence of the categories of alternative conceptions are presented in Figure 4.

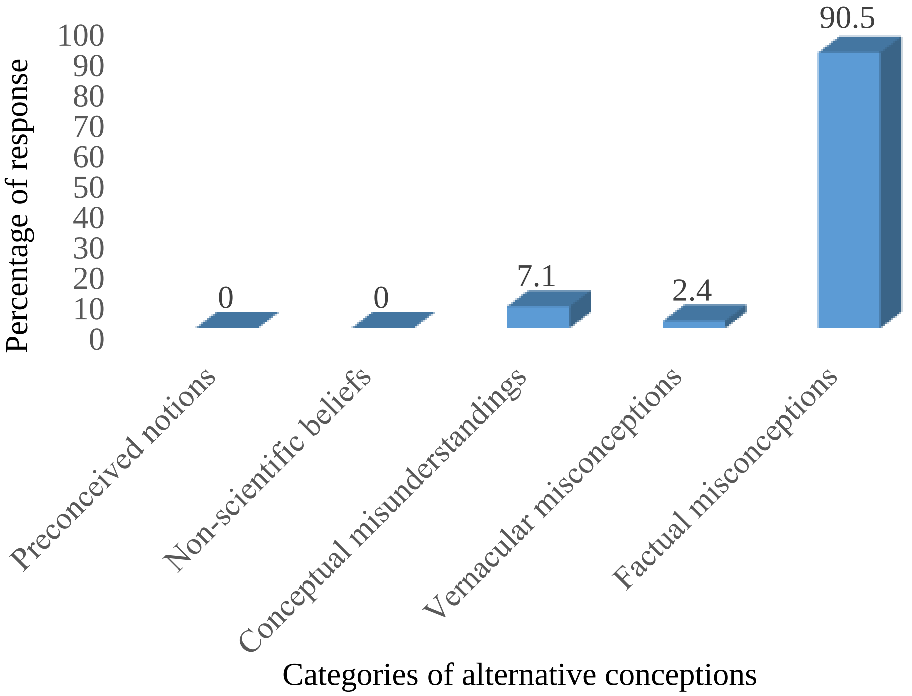


Figure 4: Bar chart of categories of students' alternative conceptions in pre-requisite concepts.

Source: Field data (Ofori-Ahenkan, 2020).

Results from Figure 4 indicated that, in the prerequisite concepts, the preconceived notions and non-scientific beliefs categories of alternative conceptions were absent, whereas the remaining three categories: conceptual misunderstandings, vernacular misconceptions, and factual misconceptions were present among the alternative conceptions identified. Most (90.5%) of the students' alternative conceptions in the prerequisite concepts existed as factual misconceptions. That is, the students' conceptions that were built on false ideas learnt at early ages and have been unchallenged till students' learning of the prerequisite concepts. For instance, students might have learnt in the early stages of chemistry that an atom must obey either the duplet or octet rule in order to achieve stability. Since boron in BF_3 has three bonding-pairs of electrons around it, some students have the notion that it must have a non-bonding pair of electrons so that it will obey the octet rule. This is inaccurate as boron in BF_3 is an exception to the octet rule. An excerpt is:

> "*In the BF_3 molecule, both elements offer 3 electrons to be shared which gives 3 bonding pairs. B element as the central atom is left with 2 electrons which don't take part in the bonding. They constitute 1 non-bonding pair*" (STC005).

Also, students might have been taught in early stages of chemistry that increasing lattice energy leads to an increase in boiling point. Lattice energy applies to only ionic bonds. Although there is an ionic character in CO_2 due to electronegativity difference between carbon an oxygen, this is not enough to make it have a lattice energy as CO_2 is formed by covalent bonding. Some of the students inaccurately explained this to mean that CO_2 has a high lattice energy and so will have a high boiling point. An excerpt is:

> "*CO_2 … has a very high lattice energy*" (STC086).

Pertaining to conceptual misunderstandings, which were conceptions developed from chemistry lessons that failed to help learners confront their own preconceived notions and non-scientific beliefs, 7.1% of the students' alternative conceptions were classified under this category. For example, from students' daily familiarities, they knew that particles of a solid are strongly bonded to each other than molecules of a liquid. However, the explanation needed here was that particles of a gas have the weakest force of cohesion among themselves. This makes them free to move and therefore break away from each other. Contrary to this explanation, some of the students used their preconceived notions on the strength of forces of attraction between solid particles and the forces between liquid molecules to explain their point, meaning that science lesson on evaporation failed to help students confront their preconceived notions which led to the inaccurate explanation by the students on why the particles of a liquid break away when it turns into gas. An excerpt is:

> "*When a liquid becomes a gas, its particles break away because the force of attraction between liquid particles are less strong than that of solid particles*" (STC089).

Furthermore, students might have had the preconceived notion that greater amount of heat would be required to make a liquid boil than to make a gas boil. However, lessons in science might have failed to help students conceptualise that nitrogen monoxide (NO) is a gas as all the other molecules; CO_2, N_2, and O_2 presented in the item. Some of the students rather conceptualised nitrogen monoxide as a liquid and used their preconceived idea to explain that nitrogen monoxide would have the highest boiling point among the compounds and molecules presented. An excerpt is:

> "*Only liquids have highest boiling point. CO_2, N_2 and O_2 are gases. Therefore, NO is a liquid and will have the highest boiling point*" (STC121).

Vernacular misconceptions, which were the inaccurate meanings students gave to scientific words in their everyday life activities on the prerequisite concepts, constituted 2.4% of the students' alternative conceptions identified. For instance, some students had conceptualised hydrogen bonding literally to mean that a type of bond in which more hydrogen atoms are present. An excerpt is:

"*AsH_3 and CH_3NH_2 are the molecules with hydrogen bonding because these contain more of hydrogen atoms*" (STC121).

Relationship between students' test achievement on prerequisite concepts and thermochemistry.

The relationship between students' achievement in the prerequisite concepts (as measured by the TPRC) and their achievement in the thermochemistry concept (as measured by the TTDTT) was examined using the Pearson product-moment correlation coefficient. The assumptions of normality, linearity, and homoscedasticity were tested in a preliminary analysis to ensure that none of these assumptions was violated. With regard to normality, the skewness value for prerequisite concepts was .238 ± .204 and that of thermochemistry was .748 ± .204, indicating that the scores from the prerequisite concepts were fairly symmetrical and the scores from the thermochemistry concept were moderately skewed. Furthermore, the kurtosis value for the scores from the prerequisite concepts was -.103 ± .406 and that of thermochemistry was .245 ± .406, meaning that the distributions for both the prerequisite concepts and thermochemistry scores had thin tails (platykurtic). These kurtosis values suggested the presence of small outliers in the two distributions. The scatter plot of the analysis is presented in Figure 5.

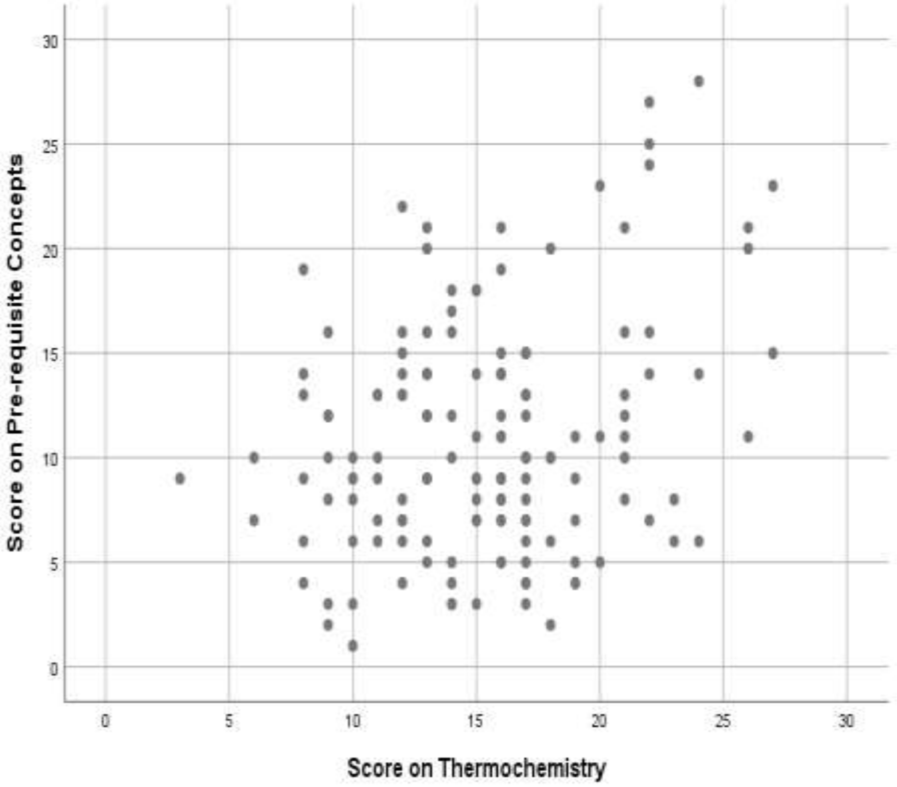


Figure 5: Scatter plot of Pearson product-moment correlation between scores in prerequisite concepts and thermochemistry scores.

Source: Field data (Ofori-Ahenkan, 2020).

From Figure 5, the results suggested a small positive significant correlation between the achievement of students in the prerequisite concepts and their achievement in thermochemistry, because the data points were seen spread all over the plotted space. Also, the scatter plot showed that there was a positive relationship between students' achievement in the prerequisite concepts and that of students' achievement in thermochemistry. Moreover, from Figure 5, there was no indication of a curvilinear relationship. Therefore, it was appropriate to calculate a Pearson product-moment correlation for the achievements of students in the prerequisite concepts and thermochemistry. The results of the Pearson product-moment correlation are presented in Table 4.

Table 4: Pearson Product-moment Correlation between Scores in Prerequisite Concepts and Thermochemistry.

Concept	Prerequisite concepts	Thermochemistry
Prerequisite Concepts		
Correlation coefficient (r)	1	.28**
p-value		.001
N	141	141
Thermochemistry		
Correlation coefficient (r)	.28**	1
p-value	.001	
N	141	141

** Correlation is significant at .01 level (2-tailed)

Source: Field data (Ofori-Ahenkan, 2020).

The results indicated that there was a small positive significant correlation between students' scores on prerequisite concepts and thermochemistry, $r = .28$, $n = 141$, $p < .01$, with a higher achievement in the prerequisite concepts associated with a higher achievement in the thermochemistry concept. The coefficient of determination, $R^2 = .28^2 = .0784$ and in percentagewise, it is 7.84%. This means that 7.84% variability of students' achievement in thermochemistry is shared by their achievement in the prerequisite concepts. Therefore, the students' achievement in the prerequisite concepts account for only 7.84% of variation in their achievement in thermochemistry, whereas the remaining 92.16% variability in their achievement in thermochemistry is accounted for by other variables.

On the relations of the students' achievement in prerequisite concepts to that of thermochemistry concept, the results showed a small positive significant correlation. This finding corroborates previous studies that there is a relationship between the prerequisite concepts (particulate nature of matter, periodicity, physical and chemical changes, and chemical bonding) and the thermochemistry concept (Ayyildiz & Tarhan, 2012; Osman & Sukor, 2013; Sheehan, 2017). However, none of these studies used statistical means to explore the magnitude and direction of the relationship as has been done in this study. A previous study that comes closer to this current study, in terms of establishing a relationship using statistical means, is the positive correlation between students' scores in particulate nature of matter and their scores in chemical bonding (Othman et al., 2008). A greater magnitude of the relationship between thermochemistry and the prerequisite concepts, other than the one found in this study, was anticipated. However, that could not be realised probably because the time gap between when the prerequisite concepts were learnt and when the thermochemistry concept was learnt was wide, leading to a weakening of the linkage between them. Despite the magnitude of the relationship being small, it is still significant and cannot be underemphasised. Further analysis of the correlation coefficient shows that 7.84% variation of the students' achievement in the thermochemistry concept can be accounted for by their achievement in the prerequisite concepts. Nonetheless, this 7.84% of similar variation between the two scores does not infer a causal relationship.

In addition to the statistically established relationship, the alternative conceptions identified in the prerequisite concepts confirms that there is an associative relation between the prerequisite concepts and thermochemistry. This can be seen in the categories of alternative conceptions identified in both the prerequisite concepts and thermochemistry. Three out of the four categories of alternative conceptions identified in thermochemistry were also identified in the prerequisite concepts. With the exception of the preconceived notions category that was identified in thermochemistry only, the three other categories shared by both the prerequisite concepts and thermochemistry are factual misconceptions, conceptual misunderstandings, and vernacular misconceptions. In both concepts, factual misconceptions recorded the highest percentage of occurrence, conceptual misunderstandings recorded the second highest percentage, and vernacular misconceptions recorded the least percentage of occurrence.

The finding shows that students' understanding of the prerequisite concepts have small significant positive correlation with their understanding of thermochemistry (Sheehan, 2017). This indicates that students' alternative conceptions in the prerequisite concepts have some translations into their alternative conceptions in thermochemistry (Barker & Miller, 2000) as indicated in the conceptual framework of this study. Therefore, what this finding implies is that the prerequisite concepts need to be taught in such a manner that there will be no or less alternative conceptions among students before teaching thermochemistry so that students' understanding of thermochemistry will be improved. Notwithstanding, the correlation coefficient being small means that there are other variables that account for a greater proportion of students' understanding of thermochemistry, which this current study could not cover and these must be investigated to further improve the teaching and learning of thermochemistry.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the summary of the study, conclusions made out of the findings of the study, and recommendations based on the findings. It also includes suggestions for further research (research gaps) that other researchers can embark on in the future.

Summary

The purpose of this study was to investigate the conceptions that SHS chemistry students have in thermochemistry and to diagnose the causes of those students' conceptions. In order to achieve the purpose, the study employed the convergent parallel mixed-methods research design which involved three stages as collection of quantitative and qualitative data (Stage 1), analysis of both quantitative and qualitative data (Stage 2), and interpretation of quantitative and qualitative results (Stage 3). The study was conducted in three selected SHS in the Cape Coast Metropolis. A multistage sampling procedure was used in selection of schools and students. All second-year General Science students formed the target population. This population was estimated to be 1,634 students. The sample size used was 141 students who responded to self-constructed data collection instruments; two separate two-tier diagnostic test instruments (TPRC and TTDTT) and a standardised open-ended interview guide. The quantitative data were analysed using frequency distributions, item difficulty index, and Pearson product-moment correlation statistic. Qualitative data were analysed thematically.

Key findings

1. Concerning the conceptual difficulties of students in thermochemistry as was the focus of this study, it was discovered that most students could not provide scientific explanations to the choice of options they selected. The number of students who could demonstrate the full scientific conceptions in thermochemistry were few. Students had alternative conceptions and other conceptual difficulties in identifying endothermic and exothermic reactions, determining heats of reactions, applying Hess' law of heat summation and the Born-Haber cycle, determining enthalpy of neutralisation reactions, energy changes associated with bond formation and bond breaking, and energy changes in foods. The categories of students' alternative conceptions identified in the thermochemistry concept were factual misconceptions, conceptual misunderstandings, preconceived notions, and vernacular misconceptions, whereas the non-scientific beliefs category was absent.
2. In relation to the factors accounting for students' alternative conceptions, teacher-related factor, textbook-related factor, and daily experiences were identified. The teacher-related factor was in the form of pedagogical skills, content knowledge, and assessment and evaluation skills. The textbook-related factor was in the form of lack of clarity of descriptions, incomprehensible terminologies, and abridged calculations. The daily experiences were mainly conceptions that the students brought into the classroom from their day-to-day activities.

3. It was also found out that there was a weak relationship between students' achievement in the prerequisite concepts and their achievement in the thermochemistry concept. The Pearson product-moment correlation coefficient (r) obtained for this relationship was .28 ($n = 141$, $p < .01$). Again, the categories of students' alternative conceptions identified in the prerequisite concepts were factual misconceptions, conceptual misunderstandings, and vernacular misconceptions, whereas the preconceived notions and non-scientific beliefs categories were absent.

Conclusions

The findings made in this study showed that chemistry students have alternative conceptions in thermochemistry and its prerequisite concepts such as particulate nature of matter, chemical bonding, physical and chemical changes, periodicity, and hybridisation and molecular geometry. These alternative conceptions result in students' inability to give correct explanations that conform to the scientific point of view (Adu-Gyamfi et al., 2015) on thermochemistry. Subsequently, such alternative conceptions lead to students' mistakes and poor performance in thermochemistry as asserted by the WAEC Chief Examiner's reports. Whereas previous studies only identified students' alternative conceptions in thermochemistry and did not categorise them, this study has contributed to literature by categorising the alternative conceptions, revealing that the religious and mythical beliefs of chemistry students do not contribute to their alternative conceptions in thermochemistry. Rather, it is the students' preconceived notions gathered from their personal daily experiences, the inability of scientific concepts to counter their preconceived notions, their construction of knowledge based on false ideas, and their usage of scientific terminologies in non-scientific contexts that constitute their alternative conceptions.

Additionally, the findings on factors that cause alternative conceptions and other conceptual difficulties among students in the thermochemistry concept are coherent with previous research findings (Demircioğlu et al., 2006; Gegios et al., 2017; Schultz et al., 2017) that the content knowledge, lesson delivery skills, and assessment and evaluation skills of teachers, as well as the students' application of knowledge constructed from personal daily experiences to classroom lessons, and some unsuitable features of textbooks used by students are the causes of their alternative conceptions in thermochemistry. Whereas previous studies have found that beliefs contribute to alternative conceptions (Taber, 2019; Yang et al., 2014), this present study has contributed to literature that concerning the thermochemistry concept, beliefs do not contribute to students' alternative conceptions. Again, this present study has an implication for policy formulation that some chemistry teachers lack pedagogical skills and mastery of chemistry content, and some policies need to be put in place to check these occurrences going forward. The factors identified in this study, to a larger extent, can be minimised to subsequently reduce students' alternative conceptions.

The finding made in this study showed that students' conceptual understanding of the particulate nature of matter, physical and chemical changes, periodicity, chemical bonding, and hybridisation and molecular geometry concepts (prerequisite concepts) had a small positive significant relationship with their conceptual understanding in the thermochemistry concept. This means that there were other variables other than the prerequisite concepts that could explain students' conceptual difficulties in thermochemistry to a greater extent. Notwithstanding, whereas existing literature assert that there is a relationship between the prerequisite concepts and thermochemistry without backing it with statistics, this study has contributed to literature by finding that statistical relationship between the prerequisite concepts investigated and the thermochemistry concept. Further, this finding contributes to the practice of teaching thermochemistry by highlighting the need to give much attention to other variables that are likely to affect students' understanding of thermochemistry rather focusing on the prerequisite concepts since the relationship established in this study is weak.

Recommendations

From the findings of this study, the following recommendations are made:

1. As there were alternative conceptions and other conceptual difficulties identified, teachers teaching chemistry in the SHS need to build their capacity on detection and correction of students' alternative conceptions to ensure that students gain scientific understanding of thermochemistry. Also, as a greater proportion of the students' alternative conceptions were factual misconceptions, teachers teaching chemistry in the SHS should probe to know the conceptions of students built on false ideas in relation to thermochemistry so that they can be challenged and corrected in the course of delivering thermochemistry lessons to improve students' understanding of the concept.

2. Since one of the factors accounting for students' alternative conceptions in thermochemistry is textbook-related, it is recommended that the National Council for Curriculum and Assessment (NaCCA) and by extension Ghana Education Service and Ministry of Education evaluate the standards of all textbooks to ensure that they do not contain features that will create alternative conceptions before approval is given for them to be sold and used in schools.
3. As there was a small significant positive correlation between students' achievement in the prerequisite concepts and their achievement in the thermochemistry concept, it is recommended that teachers teaching chemistry in the SHS pay much attention to discovering other variables that affect the students' understanding of thermochemistry and making sure that those variables will turn out to enhance understanding of thermochemistry.

Suggestions for Further Research

In probing the factors of alternative conceptions, only the students were interviewed, and no observations of lesson activities on thermochemistry was done to ascertain the responses provided by the students. Therefore, it is recommended that future researchers should employ observation methods to probe the sources of alternative conceptions by observing all activities of lessons in the classrooms.

Also, the study investigated students' conceptual difficulties in thermochemistry but could not triangulate their conceptions with their teachers. It is, therefore, recommended that chemistry educators and researchers should triangulate the conceptual difficulties in thermochemistry of students with their teachers.

Lastly, this study investigated sources of students' conceptual difficulties in thermochemistry but could not triangulate their responses with content analysis of the recommended textbook they read. Therefore, it is suggested that National Council for Curriculum and Assessment (NaCCA) and by extension Ghana Education Service and Ministry of Education should call for content analysis of the books they have recommended for SHS chemistry.

REFERENCES

Aboagye, G. K., Amponsah, K. D., & Graham, E. O. (2019). Ghanaian senior high school students' conceptions about change of state of matter. *International Journal of Science and Technology*, *8*(2), 45-63.

Adu-Gyamfi, K., & Ampiah, J. G. (2019). Students' alternative conceptions associated with application of redox reactions in everyday life. *Asian Education Studies*, *4*(1), 29-38.

Adu-Gyamfi, K., & Asaki, I. A. (2022). Teachers' conceptual difficulties in teaching senior high school organic chemistry. *Contemporary Mathematics and Science Education*, *3*(2), ep22019. Retrieved from https://doi.org/10.30935/conmaths/12382

Adu-Gyamfi, K., Ampiah, J. G., & Agyei, D. D. (2015). High school chemistry students' alternative conceptions of H_2O, OH^-, and H^+ in balancing redox reactions. *International Journal of Development and Sustainability*, *4*(6), 744-758.

Adu-Gyamfi, K., Ampiah, J. G., & Agyei, D. D. (2020). Participatory teaching and learning approach: A framework for teaching redox reactions at high school level. *International Journal of Education and Practice*, *8*(1), 106-120.

Aljunid, S. A., Mohd, S., Rashidi, C. B., Soh, P. J., & Ku Azir, K. N. (Eds.). (2018, February). Colleges students' misconception about type of bonding. In *MATEC Web of Conferences* (Vol. 150, p. 05079). EDP Sciences

Anim-Eduful, B., & Adu-Gyamfi, K. (2021). Functional groups detection: Do chemistry teachers demonstrate conceptual difficulties in teaching? *Global Journal of Human-Social Science: G Linguistics & Education, 21*(7), 46-60.

Apler, J. B. (2019). Readability, content, and mechanical feature analysis of selected commercial science textbooks intended for third grade Filipino learners. *Congent Education, 6*(1), 1-22.

Artdej, R., Ratanaroutai, T., Coll, R. K., & Thongpanchang, T. (2010). Thai grade 11 students' alternative conceptions for acid-base chemistry. *Research in Science and Technological Education, 28*(2), 16-183.

Ary, D., Jacobs, L. C., & Razavieh, A. (2010). *Introduction to research in education.* Belmont, CA: Wadsworth Cengage Learning.

Awan, A. S., & Khan, T. M. (2013). Investigating Pakistani students' alternative ideas regarding the concept of chemical bonding. *Bulletin of Education and Research, 35*(1), 17-29.

Ayyildiz, Y., & Tarhan, L. (2012). The effective concepts on stuents' understanding of chemical reactions and energy. *Hacettepe University Journal of Education, 42*, 72-83.

Ayyildiz, Y., & Tarhan, L. (2018). Problem-based learning in teaching chemistry: Enthalpy changes in systems. *Research in Science and Technological Education, 36*(1), 35-54.

Bain, K., Moon, A., Mack, M. R., & Towns, M. H. (2014). A review of research on the teaching and learning of thermodynamics at the university level. *Chemistry Education Research and Practice, 15*(3), 320-335.

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.

Barkley, E. F., & Major, C. H. (2015). *Learning assessment techniques: A handbook for college faculty*. New York: John Willey & Sons.

Becker, N. M., & Cooper, M. M. (2014). College chemistry students' understanding of potential energy in the context of atomic-molecular interactions. *Journal of Research in Science Teaching, 51*(6), 789-808.

Bordens, K. S., & Abbott, B. B. (2011). *Research design and methods: A process approach* (8th ed.). New York: McGraw-Hill.

Burrows, N. L., & Mooring, S. R. (2015). Using concept mapping to uncover students' knowledge structures of chemical bonding concepts. *Chemistry Education Research, 16*(1), 53-66.

Cape Coast Metropolitan Assembly. (2021). *About Cape Coast Metro Assembly: The Cape Coast Metropolis*. Retrieved January 2022, from Cape Coast Metropolitan Assembly Web site: http://ccma.gov.gh/ aboutccma#

Capps, D. K., McAllister, M., & Boone, W. J. (2013). Alternative conceptions concerning the Earth's interior exhibited by Honduran students. *Journal of Geoscience Education, 61*(2), 231-239.

Carson, E. M., & Watson, J. R. (2002). Undergraduate students' understanding of entropy and Gibbs free energy. *University Chemistry Education, 6*(1), 4-12.

Cetin-Dindar, A., & Geban, O. (2017). Conceptual understanding of acids and bases concepts and motivation to learn chemistry. *The Journal of Educational Research, 110*(1), 85-97.

Chang, R. (2010). *Chemistry* (10th ed.). Boston: McGraw Hill Higher Education.

Chen, F., Zhang, S., Guo, Y., & Xin, T. (2017). Applying the rule space model to develop a learning progression for thermochemistry. *Research in Science Education, 47*(6), 1357-1378.

Chrzanowski, M. M., Grajkowski, W., Żuchowski, S., Spalik, K., & Ostrowska, B. E. (2018). Vernacular minsconceptions in teaching science--Types and causes. *Journal of Turkish Science Education, 15*(4), 29-54.

Chu, H. E., Treagust, D. F., Yeo, S., & Zadnik, M. (2012). Evaluation of students' understanding of thermal concepts in everyday contexts. *International Journal of Science Education, 34*(10), 1509-1534.

Chung, D. (2011). Using diagnostic assessment to help teachers understand the chemistry of the lead-acid battery. *Chemistry Education Research and Practice, 12*(2), 228-237.

Cooper, M. M., & Klymkowsky, M. W. (2013). The trouble with chemical energy: Why understanding bond energies requires an interdisciplinary systems approach. *CBE-Life Sciences Education, 12*(2), 306-312.

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

Croft, M., & de Berg, K. (2014). From common sense concepts to scientifically conditioned concepts of chemical bonding: An historical and textbook approach designed to address learning and teaching issues at the secondary school level. *Science and Education, 23*(9), 1733-1761.

Dega, B. G., & Govender, N. (2016). Assessment of students' scientific and alternative conceptions of energy and momentum using concetration analysis. *African Journal of Research in Mathematics, Science and Technology Education, 20*(3), 201-213.

Demircioğlu, H., Demircioğlu, G., & Ayas, A. (2006). Storylines and chemistry teaching. *Hacettepe University Journal of Education, 30*(30), 110-119.

Dreyfus, B. W., Gouvea, J., Geller, B. D., Sawtelle, V., Turpen, C., & Redish, E. F. (2014). Chemical energy in an introductory physics course for the life sciences. *American Journal of Physics, 82*(5), 403-411.

Dukhan, N. (2016). Framing students' learning problems of thermodynamics. In *2016 ASEE Annual Conference and Exposition.* Louisiana, NO: American Society for Engineering Education. doi:10.18260/p.26955

Ebbing, D. D., & Gammon, S. D. (2009). *General chemistry* (9th ed.). Boston: Houghton Mifflin Company.

Eggen, P. O., Persson, J., Jacobsen, E. E., & Hafskjold, B. (2017). Development of an inventory for alternative conceptions among students in chemistry. *LUMAT: International Journal on Math, Science and Technology Education, 5*(1), 1-11.

Faizal, W. M., Helmi, M. R., Azilawaty, A. N., Nurulamirah, A., & Nurshuhada, N. (n.d.). *Students' alternative conceptions regarding the mole concept: A literature review.* Retrieved from https://www.academia.edu/9549697/Students_Alternative_%20Conceptions_Regarding_The_Mole_Concept_A_Literature_Review

Field, J., Stone, S., Orsini, C., Hussain, A., Vital, S., Crothers, A., & Walmsley, D. (2018). Curriculum content and assessment of pre-clinical dental skills: A survey of undergraduate dental education in Europe. *European Journal of Dental Education, 22*(2), 122-127.

Franco-Mariscal, A. J., Oliva-Martinez, J. M., & Almoraima Gil, M. L. (2015). Understanding the idea of chemical elements and their periodic classification in Spanish students aged 16-18 years. *International Journal of Science and Mathematics Education, 14*(5), 885-906.

Franke, G., Scharfenberg, F. J., & Bogner, F. X. (2013). Investigation of students' alternative conceptions of terms and processes of gene technology. *International Scholarly Research Notices, 2013*. Retrieved from https://downloads.hindawi.com/archive/2013/741807.pdf

Garnett, P. J., & Treagust, D. F. (1992). Conceptual difficulties experienced by senior high school students of electrochemistry: Electrochemical (galvanic) and electrolytic cells. *Journal of Research in Science Teaching, 29*(10), 1079-1099.

Garnett, P. J., Garnett, P. J., & Hackling, M. W. (1995). Students' alternative conceptions in chemistry: A review of research and implications for teaching and learning. *Studies in Science Education, 25*(1), 69-96.

Gegios, T., Salta, K., & Koinis, S. (2017). Investigating high-school chemical kinetics: The Greek chemistry textbook and students' difficulties. *Chemistry Education Research and Practice*, *18*(1), 151-168.

Gierl, M. J., Bulut, O., Guo, Q., & Zhang, X. (2017). Developing, analysing, and using distractors for multiple-choice tests in education: A comprehensive review. *Review of Educational Research*, *87*(6), 1082-1116.

González, C., Resa, J. M., Concha, R. G., & Goenaga, J. M. (2004). Enthalpies of mixing and heat capacities of mixtures containing alcohols and n-alkanes with corn oil at 298.15 K. *Journal of the American Oil Chemists' Society*, *81*(9), 817-822.

Gooding, J., & Metz, B. (2011). From conceptions to conceptual change: Tips for identifying and overcoming students' misconceptions. *The Science Teacher*, *78*(4), 34-37.

Hanson, R. (2017). Unearthing conceptions about types of chemical bonding through the use of tiered worksheets: A case study. *International Journal for Cross-Disciplinary Subjects in Education*, *8*(2), 3112-3122.

Hanson, R. (2020). Chemistry teachers' interpretation of some students' alternative conception: A pilot study. *African Journal of Chemical Education*, *10*(1), 69-96.

Hanson, R., Sam, A., & Antwi, V. (2012). Misconceptions of undergraduate chemistry teachers about hybridisation. *African Journal of Educational Studies in Mathematics and Sciences*, *10*, 45-54. Retrieved from https://www.ajol.info/index.php/ajesms/article/view/91955

Hanson, R., Taale, K. D., & Antwi, V. (2011). Investigating senior high school students' conceptions of introductory chemistry concepts. *International Journal of Educational Administration, 3*(1), 41-57.

Hanson, R., Twumasi, A. K., Aryeetey, C., Sam, A., & Adukpo, G. (2016). Secondary schoool students' conceptual understanding of physical and chemical changes. *Asian Journal of Education and Training, 2*(2), 44-52.

Harding, K. G. (2018). Heat transfer introduction. *University of the Witwatersrand: Johannesburg, South Africa*, 1-62.

Hoffman, A., & Hennessy, M. (2018). The periodic table: A framework for engaging introductory chemistry students. *Journal of Chemical Education, 95*(2), 281-285.

Howell, D. C. (2013). *Statistical methods for psychology* (8th ed.). Belmont, CA: Wadsworth Cengage Learning.

Koc, I., & Yager, R. E. (2016). Preservice teachers' alternative conceptions in elementary science concepts. *Cypriot Journal of Educational Science, 11*(3), 144-159.

Lee, C. K. (2014). A conceptual change model for teaching heat energy, heat transfer and insulation. *Science Education International, 25*(4), 417-437.

McClain, L., Gulbis, A., & Hays, D. (2018). Honesty on student evaluations of teaching: Effectiveness, purpose, and timing matter! *Assessment and Evaluation in Higher Education, 43*(3), 369-385.

Mchunu, S. P., & Imenda, S. (2013). The alternative conceptions held by high school students in mechanics. *The International Journal of Science in Society*, *4*(1), 25-42.

Meltafina, M., Wiji, W., & Mulyani, S. (2019). Misconceptions and threshold concepts in chemical bonding. In *Journal of Physics: Conference Series* (Vol. 1157, no. 4, p. 042030). Institute of Physics (IOP) Publishing.

Ministry of Education. (2010). *Teaching syllabus for chemistry (Senior High School 1-3).* Accra, Ghana: Author.

Mondal, B. C., & Chakraborty, A. (2013). *Misconceptions in chemistry: Its identification and remedial measures.* Saarbrücken: LAP Lambert Academic Publishing.

Muntholib, M. J., Pratiwi, Y. N., Muchson, M. J., & Yahmin, R. S. (2018). Development of simple multiple-choice diagnostic test of acid-base concepts to identify students' alternative conceptions. *Advances in Social Science, Education and Humanities Research*, *218*, 251-268.

National Research Council. (1997). *Science teaching reconsidered: A handbook.* Washington, DC: National Academies Press.

Omilani, N. A., & Elebute, F. D. (2020). Analysis of misconceptions in chemical equilibrium among senior secondary school students in Ilesa Metropolis in Osun State, Nigeria. *African Journal of Education Studies in Mathematics and Sciences*, *16*(2), 1-13.

Ortiz, C. B. (2019). Students' understanding of pre-organic chemistry concepts: Chemical bonding. *International Journal on Language, Research and Education Studies*, *3*(1), 33-42.

Osman, K., & Sukor, N. S. (2013). Conceptual understanding in secondary school chemistry: A discussion of the difficulties experienced by students. *American Journal of Applied Sciences*, *10*(5), 433-441.

Othman, J., Treagust, D. F., & Chandrasegaran, A. L. (2008). Investigation into the relationship between studens' conceptions of the particulate nature of matter and their understanding of chemical bonding. *International Journal of Science Education, 30*(11), 1531-1550.

Özmen, H. (2007). The effectiveness of conceptual change texts in remediating high school students' alternative conceptions concerning chemical equilibrium. *Asia Pacific Education Review, 8*(3), 413-425.

Özmen, H., Demircioglu, H., & Demircioglu, G. (2009). The effects of conceptual change texts accompanied with animations on overcoming 11th grade students' alternative conceptions of chemical bonding. *Computers & Education, 52*(3), 681-695.

Pagano, R. R. (2013). *Understanding statistics in the behavioural sciences.* Belmont, CA: Wadsworth Cengage Learning.

Page, K. (2012). Misunderstanding misconceptions. *Science Scope, 35*(8), 12-15.

Pan, L., Li, C., Li, J., & Tang, J. (2017). Prerequisite relation learning for concepts in moocs. In *Proceedings of the 55th Annual Meeting of the Association for Computational Linguistics* (*Volume 1: Long Papers)* (pp. 1447-1456).

Pathare, S., & Pradhan, H. C. (2011). Students' alternative conceptions in pressure, heat and temperature. *Physics Education, 21*(3-4), 213-218.

Pedrosa, M. A., & Dias, M. H. (2000). Chemistry textbook approaches to chemical equilibrium and student alternative conceptions. *Chemistry Education: Research and Practice in Europe*, *1*(2), 227-236.

Perez, J. R., Perez, M. E., Calatayud, M. L., Garcia-Lopera, R., Montesinos, J. V., & Gil, E. T. (2017). Students' misconceptions on chemical bonding: A comparative study between high school and first year university students. *Asian Journal of Education and e-Learning*, *5*(1), 1-15.

Quílez, J. (2019). A categorisation of the terminological sources of student difficulties when learning chemistry. *Studies in Science Education*, *55*(2), 121-167.

Rahmayani, R. F. I. (2017). Identification of student difficulties in understanding thermochemical materials using three-tier multiple choice diagnostic instruments in class XI MIA 5 MAN MODEL Banda Aceh. *Scientific Journal of Chemistry Education Students*, *2*(1), 35-44.

Rai, K. B. (2018). Design and data integration in mixed methods research: Challenges and ways forward. *Research Nepal Journal of Development Studies*, *1*(2), 131-149.

Retno, A. T., Saputro, S., & Ulfa, M. (2018). Properness test: Development of an inquiry-based learning module to improve science literacy in thermochemistry subject. In *AIP Conference Proceedings* (Vol. 2021, No. 1, p. 080003). Centra Java, Indonesia: American Institute of Physics Publishing LLC.

Rusek, M., & Vojíř, K. (2019). Analysis of text difficulty in lower-secondary chemistry textbooks. *Chemistry Education Research and Practice, 20*(1), 85-99.

Salah, H., & Dumon, A. (2011). Conceptual integration of hybridisation by Algerian students intending to teach physical sciences. *Chemistry Education Research and Practice, 12*(4), 443-453.

Salame, I. I., & Casino, P. (2021). Using chemistry concepts inventory to identify alternative conceptions and their persistence in general chemistry courses. *International Journal of Instruction, 14*(3), 787-806.

Santos, J. L., Erdmann, A. L., Meirelles, B. H., Lanzoni, M. M., Cunha, V. P., & Ross, R. (2017). Integrating quantitative and qualitative data in mixed methods research. *Texto Contexto Enferm, 26*(3), e1590016.

Saricayir, H., Ay, S., Comek, A., Cansiz, G., & Uce, M. (2016). Determining students' conceptual understanding level of thermodynamics. *Journal of Education and Training Studies*, *4*(6), 69-79.

Schmidt, H. J., Marohn, A., & Harisson, A. G. (2007). Factors that prevent learning in electrochemistry. *Journal of Research in Science Teaching, 44*(2), 258-283.

Schoon, K. J. (1995). The origin and extent of alternative conceptions in the earth and space sciences: A survey of pre-service elementary teachers. *Journal of Elementary Science Education, 7*(2), 27-46.

Schultz, M., Lawrie, G. A., Bailey, C. H., Bedford, S. B., Dargaville, T. R., O'Brien, G., . . . & Wright, A. H. (2017). Evaluation of diagnostic tools that tertiary teachers can apply to profile their students' conceptions. *International Journal of Science Education, 39*(5), 565-586.

Sheehan, M. (2017). *Perspectives on the problem of alternative conceptions* (Doctoral thesis, University of Limerick). Retrieved from http://hdl.handle.net/10344/6569

Shivabasappa, K. L., Babu, P. N., & Rao, Y. J. (2008). Enthalpy of mixing and heat of vapourization of ethyl acetate with benzene and toluene at 298.15 K and 308.15 K. *Brazilian Journal of Chemical Engineering, 25*(1), 167-174.

Sokrat, H., Tamani, S., Moutaabbid, M., & Radid, M. (2014). Difficulties of students from the Faculty of Science with regard to understanding the concepts of chemical thermodynamics. *Procedia-Social and Behavioural Sciences, 116*, 368-372. Retrieved from https://doi.org/10.1016/j.sbspro.2014.01.223

Sreenivasulu, B., & Subramaniam, R. (2013). University students' understanding of chemical thermodynamics. *International Journal of Science Education, 35*(4), 601-635.

Taber, K. S. (2009). *Progressing Science Education: Constructing the scientific research programme into the contingent nature of learning science.* Dordrecht: Springer.

Taber, K. S. (2015). Alternative conceptions/frameworks/misconceptions. In R. Gunstone (Ed.), *Encyclopedia of Science Education* (pp. 37-41). Berlin-Heidelberg: Springer-Verlag.

Taber, K. S. (2019). Alternative conceptions and the learning of chemistry. *Israel Journal of Chemistry, 59*(6-7), 450-469.

Thonney, T. (2016). Analyzing the vocabulary demands of introductory college textbooks. *The American Biology Teacher, 78*(5), 389-395.

Turk, F., & Calik, M. (2008). Using different conceptual change methods embedded within 5E model: A sample teaching of endothermic-exothermic reactions. *Asia-Pacific Forum on Science Learning and Teaching, 9*(1), 1-10.

Uce, M. (2015). Constructing model in teaching of chemical bonds: Ionic bond, covalent bond, double and triple bonds, hydrogen bond and molecular geometry. *Educational Research and Reviews, 10*(4), 491-500.

Uyulgan, M. A., Akkuzu, N., & Alpat, S. (2014). Assessing the students' understanding related to molecular geometry using a two-tier diagnostic test. *Journal of Baltic Science Education, 13*(6), 839-855.

Uzezi, J. G., Ezekiel, D., & Auwal, A. K. M. (2017). Assessment of conceptual difficulties in chemistry syllabus of the Nigerian science curriculum as perceived by high school college students. *American Journal of Educational Research, 5*(7), 710-716.

Vorsah, R. E., & Adu-Gyamfi, K. (2021). High school chemistry teachers' perspectives and practices on teaching mole concept. *European Journal of Education Studies, 8*(2), 132-151.

Vrabec, M., & Prokša, M. (2016). Identifying misconceptions related to chemical bonding concepts in the Slovak school system using the bonding representations inventory as a diagnostic tool. *Journal of Chemical Education, 93*(8), 1364-1370.

WAEC. (2011). *Chief examiner's report for science.* Accra: Author.

WAEC. (2013). *Chief examiner's report for science.* Accra: Author.

WAEC. (2018). *Chief examiner's report for science.* Accra: Author.

Wiji, W., & Mulyani, S. (2018). Student's mental model, misconceptions, troublesome knowledge, and threshold concept on thermochemistry with DToM-POE. *Journal of Physics: Conference Series. 1013*, p. 012098. IOP Publishing.

Woldamanuel, M. M., Atagana, H., & Engida, T. (2015). Students' conceptual difficulties in thermodynamic. *Chemical Science Review and Letters, 4*(13), 299-309.

Wolfram, W. (2011). Changing misconceptions about dialect diversity: The role of public education. *CAL Digest*. Washington, DC: Center for Applied Linguistics.

Wren, D., & Barbera, J. (2014). Psychometric analysis of the thermochemistry concept inventory. *Chemistry Education Research, 15*(3), 380-390.

Yang, C., Noh, T., Scharmann, L. C., & Kang, S. (2014). A study of the elmentary school teacher's awareness of students' alternative conceptions about change of states and dissolution. *The Asia-Pacific Education Researcher, 23*(3), 683-698.

APPENDICES

APPENDIX A

TEST ON PREREQUISITE CONCEPTS (TPRC)

Dear Student,

This test seeks to identify your understanding in some selected chemistry concepts. Kindly be informed that this test is conducted for a research purpose only and not to grade you by your teachers. Please respond to all the items with all **seriousness** and do an **independent** work. Be assured that your identity will be kept confidential. Thank you for your cooperation.

Date: __________________ Reference Number: ______________

Sex: ____________________ Age: ___________________

School-type: _______________________

INSTRUCTION: Choose among the options lettered A-D, which best answers each question. Afterwards, provide a brief justification for the answer chosen in the empty spaces provided.

1. The number of valence electrons present in IIA compared to VA are ____.

   A. 2 and 2

   B. 2 and 5

   C. 2 and 6

   D. 6 and 2

   Explain your answer

   ……………………………………………………………………………………

   ……………………………………………………………………………………

   ……………………………………………………………………………………

   ……………………………………………………………………………………

2. Which **one** of the following statements concerning elements in the Periodic Table is correct?

   A. Elements of the same group all have the same number of electrons in the outermost occupied electron shell.

   B. Oxides of elements in Groups 16 and 17 are basic.

   C. The Group 13 elements are all metals.

   D. The halogens (Group 17) are all gases at room temperature.

   Explain your answer

   …………………………………………………………………………………

   …………………………………………………………………………………

   …………………………………………………………………………………

   …………………………………………………………………………………

3. The major intermolecular force in $\mathbf{I_2}$ is ______________.

   A. covalent bonds

   B. dipole-dipole forces

   C. hydrogen bonds

   D. ionic bonds

   Explain your answer

   …………………………………………………………………………………

   …………………………………………………………………………………

   …………………………………………………………………………………

   …………………………………………………………………………………

4. Which of the following molecules/pairs of molecules have their intermolecular forces to be hydrogen bonds?

   CH_4, AsH_3, CH_3NH_2, H_2Te

   A. AsH_3, CH_3NH_2

   B. AsH_3, H_2Te

   C. CH_3NH_2

   D. CH_4, AsH_3, H_2Te

   Explain your answer

   ……………………………………………………………………………………….

   ……………………………………………………………………………………….

   ……………………………………………………………………………………….

   ……………………………………………………………………………………….

5. The specie that does not contain a sp^3-hybridised atom is ………………

   A. BH_3

   B. BH_4^-

   C. NH_3

   D. NH_4^+

   Explain your answer

   ……………………………………………………………………………………….

   ……………………………………………………………………………………….

   ……………………………………………………………………………………….

   ……………………………………………………………………………………….

6. Which of the following has the **lowest** boiling point at 1 atm?

   A. HBr

   B. HCl

   C. HF

   D. H_2SO_4

   Explain your answer

   …………………………………………………………………………………

   …………………………………………………………………………………

   …………………………………………………………………………………

   …………………………………………………………………………………

7. The atomic number of the element in whose atom the K and L shells are full is ……………………

   A. 10

   B. 12

   C. 14

   D. 16

   Explain your answer

   …………………………………………………………………………………

   …………………………………………………………………………………

   …………………………………………………………………………………

   …………………………………………………………………………………

8. Which **one** of the following substances will have the highest boiling point?

   A. CO_2

   B. N_2

   C. NO

   D. O_2

   Explain your answer

   ………………………………………………………………………………………

   ………………………………………………………………………………………

   ………………………………………………………………………………………

   ………………………………………………………………………………………

9. How many sigma and pi bonds are there in C_2H_4?

   A. 1 sigma- and 1 pi-bond

   B. 1 sigma- and 5 pi-bonds

   C. 4 sigma- and 2 pi-bonds

   D. 5 sigma- and 1 pi-bond

   Explain your answer

   ………………………………………………………………………………………

   ………………………………………………………………………………………

   ………………………………………………………………………………………

10. How many bonding and **non**-bonding electron pairs are found in the BF_3 molecule?

    A. 1 bonding and 3 non-bonding electron pairs

    B. 3 bonding and 1 non-bonding electron pairs

    C. 3 bonding and 0 non-bonding electron pairs

    D. 4 bonding and 0 non-bonding electron pairs

Explain your answer

…………………………………………………………………………...………

……………………………………………………………………..……………

………………………………………………………………………………….

….……………………………………………………………………………...…

11. What is the geometry of the **NH_3** molecule?

A. Linear

B. Square pyramidal

C. Tetrahedral

D. Trigonal pyramidal

Explain your answer

………………………………………………………………………………..

………………………………………………………………………………….

…….…………………………………………………………………………

………..………………………………………………………………………

12. The main energy level that can hold only **two** electrons is the __________ level.

A. 1st

B. 2nd

C. 3rd

D. 4th

Explain your answer

…………………………………………………………..……………………

…………………………………………………………………...……………

………………………………………………………………………….….

13. When a liquid becomes a gas, the particles ………………………………

    A. break away

    B. maintain their distance

    C. move closer together

    D. move slowly

    Explain your answer

    ……………………………………………………………………………..………

    …………………………………………………………………………….….

    …………………………………………………………………………..……

14. What accounts for electrons spending more time in the vicinity of one atom than another in a molecule?

    A. Diamagnetism

    B. Electron charge-to-mass ratio

    C. Electronegativity

    D. Paramagnetism

    Explain your answer

    …………………………………………………………………………………

    …………………………………………………………………………………

    …………………………………………………………………………………

    …………………………………………………………………………………

APPENDIX B

TWO-TIER DIAGNOSTIC TEST ON THERMOCHEMISTRY (TTDTT)

Dear Student,

This test seeks to identify your understanding on thermochemistry. Kindly be informed that this test is conducted for a research purpose only and not to grade you by your teachers. Please respond to all the items with all **seriousness** and do an **independent** work. Be assured that your identity will be kept confidential.

Date: ____________________ Reference Number: _____________

Age: _____________________ Sex: ______________

School-type: _______________

INSTRUCTION: Choose among the options lettered A-D, one which best answers each question. Afterwards, provide a brief justification for the answer chosen in the empty spaces provided.

1. The enthalpy of a neutralisation reaction is _____________.

   A. always zero

   B. always greater than zero

   C. always less than zero

   D. either less than zero or greater than zero

   Explain your answer

   ……………………………………………..……………………………

   ..………………..……………………………………………….……………

   …..…………………………………………………………………...………

2. When energy is changed from one form to another, _____________.

   A. a physical change occurs

   B. all of the energy can be accounted for

   C. all of the energy is changed to a useful form

   D. some of the energy is lost entirely

   Explain your answer

   ……………………………………………………...……………………...…

   ……………………..……………………………………………………………

   ……..……………………………………………………………………………

3. The reaction, $4Al_{(s)} + 3O_{2(g)} \longrightarrow 2Al_2O_{3(s)}$ $\Delta H^o = -3351kJ$,

   is __________, and therefore heat is __________ by the reaction.

   A. endothermic, absorbed

   B. endothermic, released

   C. exothermic, absorbed

   D. exothermic, released

   Explain your answer

   ………………………………………………………………………………………

   …...……………..……………………………………………………………………

   ………………………………………………………………………..……………..

4. Which **one** of the following is the correct equation for the condensation of water?

   A. $\text{heat} + H_2O_{(l)} \longrightarrow H_2O_{(g)}$

   B. $\text{heat} + H_2O_{(g)} \longrightarrow H_2O_{(l)}$

   C. $H_2O_{(l)} \longrightarrow H_2O_{(g)} + \text{heat}$

   D. $H_2O_{(g)} \longrightarrow H_2O_{(l)} + \text{heat}$

Explain your answer

…………………………………………...……………...…..…………

…………………..……………………………………..…………..…

………………………………………………………………………

……..……………………………………………………..…………

5. What volume of H_2 at STP reacts if 155KJ is released from the reaction:

   $C_2H_{2(g)} + 2H_{2(g)} \longrightarrow C_2H_{6(g)} + 310\text{ kJ}$

   A. 5.75 L

   B. 11.2 L

   C. 22.4 L

   D. 44.8 L

   Explain your answer

   ………………………………………………………………………

   ………...……………………………………………………………

   ………………………………………………………………………

   ………………………………………………………………………

6. What is the value of ΔH_{rxn} for the reaction $PCl_{5(g)} + 4H_2O_{(l)} \longrightarrow H_3PO_{4(aq)} + 5HCl_{(aq)}$; if 65.0g PCl_5 (MM: 208 g/mol) reacts, and 72 kJ of energy is released?

   A. –230 kJ/mol

   B. –23 kJ/mol

   C. +23 kJ/mol

   D. +230 kJ/mol

   Explain your answer

……………………………..……………………………………..……..…

……………….………………………………………………..……………

……………………………………………………………………………

….….………………………………………………………..………

7. What is the enthalpy change for the reaction: $2S_{(s)} + 3O_{2(g)} \longrightarrow 2SO_{3(g)}$, which occurred through the steps of reactions below?

$S_{(s)} + O_{2(g)} \longrightarrow SO_{2(g)}$ $\Delta H_{rxn} = -297$ kJ/mol (step 1)

$2SO_{2(g)} + O_{2(g)} \longrightarrow 2SO_{3(g)}$ $\Delta H_{rxn} = -198$ kJ/mol (step 2)

A. -792 kJ/mol

B. -495 kJ/mol

C. -396 kJ/mol

D. +396 kJ/mol

Explain your answer

……………………………………………….………………………...…………

…………….…………………………...…………………………………………

…………………………………………………………….…………………..…

8. What is the ΔH^o for the reaction: $2NH_{3(g)} \longrightarrow N_{2(g)} + 3H_{2(g)}$; given the following equation and its enthalpy of reaction: $N_{2(g)} + 3H_{2(g)} \longrightarrow 2NH_{3(g)}$ $\Delta H^o = -92.6$ kJ?

A. -185.2 kJ

B. -92.6 kJ

C. 0 kJ

D. +92.6 kJ

Explain your answer

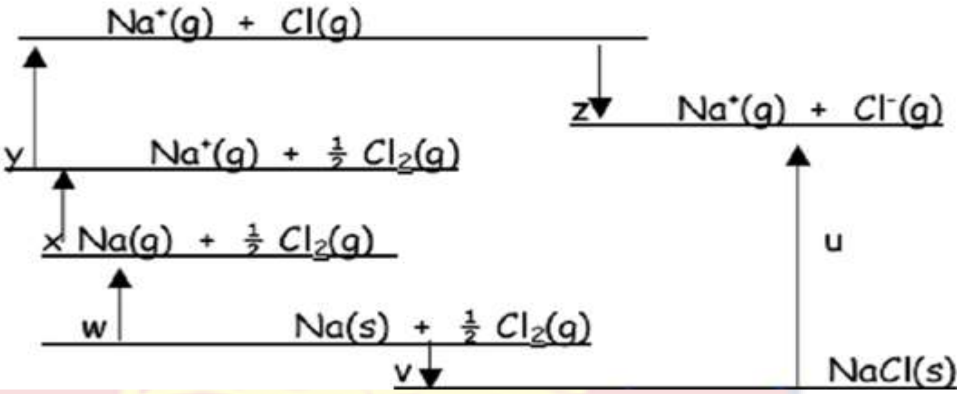
…………………………………...……..………….………………………

…………..……………………………………………....….………………

……………………………………………………………..…………………

……………………………………………………………..………….………

9. Which of these statements is correct about the diagram represented below for the Born-Haber cycle for sodium chloride?



A. electron affinity of Cl is z.

B. enthalpy of ionisation of Na is y.

C. first ionisation energy of Na is w.

D. lattice energy of NaCl is v.

Explain your answer

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

10. What is the standard enthalpy of formation of molecular oxygen (O_2)?

A. -249.2 kJ/mol

B. -241.8 kJ/mol

C. 0 kJ/mol

D. 142.7 kJ/mol

Explain your answer

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

11. The standard heat of reaction for the reaction below is …………………..

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

(ΔH^o_f of Cu^{2+} = +64.4 kJ/mol; ΔH^o_f of Zn^{2+} = –152.4 kJ/mol)

A. 88.0 kJ absorbed per mole

B. 88.0 kJ released per mole

C. 216.8 kJ absorbed per mole

D. 216.8 kJ released per mole

Explain your answer

……………………………………………………………………………………..

…………………………………………………………………………………….

……………………………………………………………………………………..

………………………………………………………………………………………

12. In which order will you add concentrated sulphuric acid ($H_2SO_{4\,(aq)}$) and water during a dilution process?

A. Add $H_2SO_{4\,(aq)}$ and water simultaneously into a beaker.

B. Add $H_2SO_{4\,(aq)}$ to water.

C. Add water and $H_2SO_{4\,(aq)}$ in a weak acid.

D. Add water to $H_2SO_{4\,(aq)}$.

Explain your answer

……………………………………………………………………..……..……

…………………..………………………………………………………..….……

………………………………………………………………………………………

…..…………………………………………………………………..………

13. What is the difference in the release of heat when you compare the complete breakdown of sugar by your body to burning the same amount of sugar in a flame?

    A. Less heat is released by the body as compared to flame.

    B. More heat is released by the body as compared to the flame.

    C. No heat will be released by the body.

    D. The same amount of heat will be released in both processes.

    Explain your answer

    ……………………………………………………..…………..……………

    …..……………………………………………………………...…………………

    ………………………………………………………………………………………

    ………………………………………………………………………………………

14. What is the enthalpy change likely to be if there are neutralisation reactions between a strong acid and a strong base, and between a weak acid and a strong base?

    A. Both will have the same enthalpy change value.

    B. Enthalpy change is immeasurable for a weak acid and a strong base.

    C. Greater for a strong acid and strong base than for a weak acid and strong base.

    D. Greater for a weak acid and strong base than for a strong acid and strong base.

    Explain your answer

    ……………………………………………………….………..……..………

    …..…………………………………………………………………...…………

    ………………………………………………………………………………………

    ………………………………………………………………………………………

15. The enthalpy change value for the **combustion** of glucose is …………………. if the equation for glucose formation and its ΔH° value are:

$6CO_{2(g)} + 6H_2O_{(l)} \longrightarrow C_6H_{12}O_{6(s)} + 6O_{2(g)}$ $\Delta H^\circ = +2.8 \times 10^3$ kJ.

A. -2.8×10^3 kJ

B. -1.4×10^3 kJ

C. $+2.8 \times 10^3$ kJ

D. $+5.6 \times 10^3$ kJ

Explain your answer

………………………………………………………………………………………

………………………………………………………………………………………

……………………………………………………………………………………..

………………………………………………………………………………………

APPENDIX C

INTERVIEW ON FACTORS ON ALTERNATIVE CONCEPTIONS IN THERMOCHEMISTRY (IFACT)

1. Do you relate your daily experiences to classroom lessons? If yes, describe how you relate your daily life experiences to classroom lessons.
2. Do you understand when your teacher teaches? Explain why.
3. How different is your teacher’s note from that of the textbook you are using?
4. How does your chemistry teacher teach you chemistry lessons?
5. What is your opinion about the knowledge of your teacher in thermochemistry?