UNIVERSITY OF CAPE COAST

AN INVESTIGATION INTO DEVELOPMENT OF SCIENCE PROCESS SKILLS BY SENIOR HIGH SCHOOL CHEMISTRY STUDENTS

ANTHONY KOOMSON

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BY

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DECLARATION

Candidate’s Declaration

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

Candidate’s Signature ……………………………….. Date …………………..

Name: Anthony Koomson

Supervisors’ Declaration

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

Principal Supervisor’s Signature ………………………. Date ……………...

Name: Prof. Joseph Ghartey Ampiah

Co-Supervisor’s Signature …………………………….. Date ……………….

Name: Prof. Christian Anthony-Krueger

ABSTRACT

This study investigated science process skills developed by chemistry students and assessed by West African Examination Council (WAEC) in chemistry education at the Senior High School (SHS) level in Ghana using a descriptive survey with a mixed-method approach. This approach analysed the content of the 2010 Chemistry syllabus and the WAEC chemistry papers 2 & 3 (2012 to 2016) to understand the types and the occurrences of science process skills developed by teachers and which ones were assessed. The study used multi-stage sampling technique to select 904 students and 85 teachers from category A, B and C schools covering 12 education districts in the Central Region of Ghana. Data were collected using questionnaires, document analysis and achievement test instruments. The study revealed that science process skills developed and assessed in chemistry education at the SHS level were mainly communicating, recording, and calculating. Achievement test for the 904 selected students corroborated with the document analysis to show that science process skills like inferring, predicting, classifying and integrated science process skills were not well developed. Literacy, laboratory and problem solving activities were found to be the three main avenues available to help students develop science process skills at the SHS level. The research suggests that skills like inferring, predicting, classifying and integrated science process skills should be emphasised in the WAEC SHS examinations and in the school curriculum. Also, workshops should be organised by GES to sensitise SHS teachers on the need for their students to develop science process skills during teaching and that these skills need to be assessed during school-based assessment.

KEY WORDS

Development of science process skills

Basic science process skills

Integrated science process skills

Skills and processes in scientific inquiry

Centrality of science process skills

Model of school science

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DEDICATION

To my mother, wife and daughters

TABLE OF CONTENTS

CHAPTER ONE: INTRODUCTION

CHAPTER TWO: LITERATURE REVIEW

CHAPTER THREE: RESEARCH METHODS

CHAPTER FOUR: RESULTS AND DISCUSSION

CHAPTER FIVE: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

Analysis of the Chief Examiners Report of practical paper, Chemistry Paper 3 from 2012 to 2016 of West African Examination Council is consistent with Ampiah's (2004) assertion that students persistently perform poorly in chemistry practicals, but it also reveals that the poor performance stems from poor performance in the question 2 in the practical paper. The question 2 examines science process skills especially the higher ones like observation, communication of results, inferences and drawing of conclusions. It can be postulated that development of higher order science process skills among students at the Senior High School (SHS) level is poor, and hence the poor results. This study seeks to investigate how science process skills are developed via chemistry education at the SHS level.

Background of the Study

Teaching and learning about science involve three important areas- scientific knowledge, science process skills and scientific attitude (Harlen, 1999). Scientific knowledge involves the content of science, its basic concepts, principles and laws. Traditionally, teaching and learning of science has placed much more emphasis in this area of science to the extent that issues of over emphasis have been raised. For example, Gilbert (2006), Pilot and Bulte (2006) and Millar and Osborne (2000) have all elaborated the effect of curricular emphasis and accumulation of only scientific knowledge.

The science process skills are the processes of doing science. These are the skills that scientists use in the process of doing science (Mutlu & Temiz, 2013). Since these skills involve asking questions and finding answers to questions, they seem to be essential skills needed in all life endeavours (Harlen, 1999). Implicitly, developing science process skills in students is providing essential tools to the students to use in the future in every area of their lives.

Science process skills to be developed by students, which are the focus of this study, consist of basic science process skills and integrated science process skills (Molefe & Stears, 2014). Basic science process skills include Observation; Communication; Classification; Measurement; Inference and Prediction whilst integrated science process skill consists of Controlling Variables; Hypothesising; Experimentation and Data Interpretation (Zeidan & Jayosi, 2014). Whereas there are empirical evidence supporting the need for an operational stage to acquire the basic skills, research suggests positive and high correlation between integrated skills and formal operational stage of development (Aydogdu, 2015).

Science process skills have long been advocated in science education (Padilla, 1990; Saçkes, 2013). Saçkes for instance undertook longitudinal studies involving 8,731 Kindergarten children (about 5-6 year olds) with the aim to investigate the factorial structure of the children's mathematics and science process skills, and the impact on their performance on mathematics and science achievement tests in the 3rd grade (8-9 year olds). The multilevel structural equation modeling tool used to analyze the data revealed that both mathematics and science process skills are among the key determinants of the children's success at the 3rd grade. Saçkes suggested that the development of children's science and mathematics process skills should be supported in the mathematics and science education. The approach to this suggestion involves the utilization of integrated inquiry-based science and mathematics activities. Saçkes not only believes that this approach will contribute to children's later academic achievement particularly in the area of science and mathematics but also certain in the ability of the approach to help children make connectivity between the two subjects.

The long standing promotion of science process skills in science education is inherently linked to its importance. Science process is linked to other scientific skills like critical and logical reasoning.

It cannot be denied that science process skills are essential for effective scientific thinking and research skills (Mutlu & Temiz, 2013). Aydoğdu, Tatar, Yıldız-Feyzioğlu and Buldur (2012) assert that science process skills are among the most frequently used thinking skills. Not only do science process skills enable individuals or students to gather information (Aydogdu, 2015), but also, by their nature, are tools for acquiring information about the world, and the means for ordering such information (Ostlund, 1992). These attributes of acquiring and ordering information places science process skills in the heart of science. Tobin and Capie cited in Aydogdu (2015), define science process skills as 'identifying a problem, formulating a hypothesis about the problem, making valid predictions, identifying and defining variables, designing an experiment to test the hypothesis, gathering and analysing data and presenting rational findings that support the data' (p. 583). It is obvious that these skills are used by scientists during their work (Mutlu & Temiz, 2013), and justifies the acquisition of these skills as an important aim of science education.

It has however, been argued that these skills are merely characteristics of many human endeavours (Harlen, 1999). Harlen does not dispute that the skills are essential, she only disagrees with its scientific tag. Her position however, strengthens making the acquisition of process skills an aim of science education. This is especially valid where science education is compulsory at the pre-university level. In this case, students who proceed to have careers in science and those who pursue non-science careers will both benefit from such skills. Such aim is also important in view of the fact that we live in a rapidly changing world with its technological advances. The boundaries of science, technology, society and environments are becoming increasingly difficult to distinguish (Pedretti, 2005). Everyday society is confronted with concerns such as genetic engineering, water and waste management, environmental degradation and other socio-scientific issues. Science process skills are needed to mitigate these everyday issues (Aydogdu, 2015). In fact, Rillero (1998) adds that it is almost impossible to succeed daily life without these skills. Though the need to incorporate development of science process skills in science education may receive general consensus, the approach may be met with divergent views. Gott and Murphy (1987) suggested that science process skills are transferable and need to be taught independently. They observed the variation in students' performance on investigation tasks. Their observation revealed that students' failure in enquiry is knowledge-based rather than skills-based. To them students' problems were due to lack of knowledge and understanding of scientific procedures or strategies of scientific enquiry. They therefore, subsumed science process skills into the concept they called procedural knowledge and consequently called for it to be taught explicitly. However, the transferability of these skills have been put to question (Ault & Dodick, 2010), with Molefe and Sears (2014) sharing the view that teaching of skills out of context is not meaningful and such decontextualized approach does not lead to conceptual development. Leggett, Kinnear, Boyce and Bennett (2004) support this view by arguing that the three areas of science- development of skills, knowledge and attitudes should be taught in line with the context in which they occur. Abrahams and Millar (2008) have specified that practical activities are the appropriate context to use. They emphasised the importance of developing conceptual understanding in science while engaging in practical activities to enhance the development of process skills. Ornstein (2006) also agrees to the use of practical activities as a medium for developing science process skills by stressing that hands-on laboratory activity and high levels of experimentation are essential for the development of such competencies. Wellington cited in Ampiah (2004) favours practical works by identifying three important use of practical activities as follows: (a) practical work can improve pupils' understanding of science and promote conceptual development; (b) practical work is motivating and exciting and helps learners to remember things; (c) practical work develops not only manipulative skills or manual dexterity skills, but also promotes higher level, transferable skills such as observation, measurement, prediction and inference.

In Ghana, the content of the teaching syllabus is determined by the Curriculum Research and Development Division (CRDD) of the Ghana Education Service (GES) with the West African Examinations Council (WAEC) being the examining body. Both bodies place emphasis on practical activities and development of experimental methods by students. For example, the chemistry syllabus for SHS developed by CRDD devotes two out of the total of six periods per week for practical work at all levels (MoE, 2010). The MoE document places 30% weight on the development of science process skills, which include 'Equipment Handling; Planning and Designing of Experiments; Observation; Manipulation; Classification; Drawing; Measuring; Interpretation; Recording; Reporting; and Conduct in Laboratory/Field' (p. x). The WAEC examination for the SHS consists of three Papers: Paper 1; Paper 2 and Paper 3. While the Paper 1 and Paper 2 assess students' Knowledge and Understanding, and Application of Knowledge, the Paper 3 is dedicated to examining practical and experimental skills (MoE, 2010). The Paper 3 consists of three questions. The first question examines students' ability to follow instructions, manipulate equipment and record values. The candidate then communicates the repeated experimental (titrimetric) value in a table and use algorithmic procedure and mole concept to measure the quantitative content of an unknown sample through calculations. The second question examines the science process skills like observations, communications, classifications, inferences and drawing of conclusions. In this question, students are to investigate qualitative content of unknown samples. This experimentation is done perhaps, in what can be described 'contingent control' (Millar, 1991) manner by giving some sort of directives and guidance. Students are expected to communicate their experiment in a table form describing specific experiments (test) executed, observations made and inferences/conclusion drawn from the experiments. The third question tests students' knowledge and familiarity of suggested practical activities in the chemistry syllabus. Practical work is an integral part of all the three sciences (Biology, Chemistry and Physics) curricula at the Ghanaian Senior High School (SHS) level (Ampiah 2004). Ampiah indicates that conventional laboratories are not only the place to develop scientific skills by stating:

> However, there are other objectives stated in the science syllabuses which relate to the acquisition of scientific skills but do not necessarily need conventional laboratories to achieve them. These objectives are summarized as follows: (a) acquisition of the necessary scientific skills for example, classifying and interpreting biological data; (b) acquisition of scientific attitudes for problem solving; (c) appreciation of the scientific method which involves deduction and interpretation of scientific data; (d) development of attitudes relevant to science such as concern for accuracy and precision, objectivity, integrity, initiative and inventiveness; and (e) development of scientific skills and attitudes as pre-requisites for further scientific activities (Ampiah, 2004, p. 51).

Though the above clearly show some of the curricular intentions of CRDD to help develop scientific skills, there is no guarantee that these skills will be developed when students are exposed to practical activities or at the end of students' programme at the SHS level (Osborne, 2015).

Osborne (2015) for instance suggests that, the overwhelming picture that emerges most of the time from research on school practical work is that students just become active during practical activities without connecting their activities to the intended aims of such activities. Watson, Swain and McRobbie cited in Osborne (2015) observed 12 -13 year olds and examined the quality of their discussions surrounding practical work. They concluded that: (a) much of the work was just repetition; (b) students did not know the purpose of their activities; (c) students did not discuss conceptual link that make sense of their result and (d) students failed to seek explanation to their results or discuss the strength of their result. Abrahams and Millar (2008) also observed that almost all students' discussion of practical activities is focussed on the manual manipulation skills involved in such activities. This leaves out many important science process skills especially the higher ones such as observation, inferences, prediction and hypothesising.

Millar (1991) categorises observation, inferences, prediction and hypothesising as high-level cognitive skills and argues that their teaching and development is not tenable under practical work. Millar divides practical skills into three subcategories, including general cognitive processes, practical techniques and inquiry tactics. The practical techniques are the 'specific know-how about selection and use of instruments including measuring instruments and how to carry out standard procedures' (p. 51), and inquiry tactics 'include repeating measurements and taking average; tabulating and graphing results in order to see trends and patterns more closely; considering an investigation in terms of variables to be altered, measured, controlled; and so on' (p. 51). Whereas he contends that the subcategory of general cognitive processes cannot and need not be taught, he maintains that the subcategories of practical techniques and inquiry tactics can be taught and improved. The basis for the notion that science process skills cannot (and need not) be taught is partly because these skills are 'theory laden' (p. 48) and also partly because development of cognitive skills are limited by genetic epistemological stage

(Monk, 1990). For instance, thousands of students located in different areas/regions in Ghana added few drops of potassium hexacyanoferrate (II) solution [$K_4Fe\ (CN)_6$] to a specific amount of a particular chemical labelled sample C during WAEC practical examination, though all of them saw and gave the same observation, according to the Chief Examiners Report, all of them nevertheless, observed wrongly. 'For $C_{(aq)}$ + $K_4\ [Fe(CN)_6]$ activity, many candidates gave the observation as blue-black precipitate instead of blue-black colouration' (Chief Examiners Report, 2012, p. 221). These students observed wrongly because their prior knowledge of what precipitate is, is in direct conflict with scientifically acceptable view of precipitate.

This shows that in order to observe correctly, the observer needs certain acceptable prior knowledge or expectation, and needs to know the relevant feature(s) of the situation under observation to pay attention to. The fact that a six year old pupil can observe that the flame of a candle goes out when covered with a gas jar does not mean that he/she can detect the formation of cloudy ammonium chloride at the point of intersection of ammonia and hydrogen chloride gases. This is because the quality of observation in a new domain depends on the student's concepts and theoretical ideas about the new domain (Millar, 1991). On the basis of genetic epistemology however, the example of cognitive acceleration in science education (CASE) shows that correct stimulation of students' environment promotes cognitive development. It is therefore possible that when a conducive environment is created to motivate and stimulate interest in students, their science process skills can be developed and used to explore and understand scientific ideas and concepts. Hence, the role of the teacher becomes crucial to the development of science process skills.

Ornstein (2006) states that students' acquisition of skills depends on the importance teachers attach to such skills. In fact, Coil, Wenderoth, Cunningham and Dirks (2010) argue that teachers' perception of science process skills and/or lack of a framework in which to work with new content, have a major influence on learning of science process skills by students. It follows therefore, that teachers' views are key determinant of how they facilitate their students' learning of scientific knowledge, and the associated acquisition of practical skills and techniques (Coll & Eames, 2008). Aydogdu (2015) raises not only the need to understand teachers' views regarding the importance they attached to science process skills but also the accompanying praxis frame of teachers' view which informs practice and development of science process skills in students.

Anecdotally, a recall of writing an experimental report in the researcher's first semester at the university for first degree in chemistry is necessary to illustrate the issue of tension between theory and practice (praxis). The experiment involved reacting magnesium and EDTA (a chelating agent). The teaching assistant (TA) in my tutoring group informed the group that the EDTA reacts with all metals in the ratio 1:1. Knowing the combining power of both species, the researcher asked for explanation, which revealed that the TA did not understand why. The rest of the tutoring group accepted the TA's view but the researcher carried on with the report with the understanding based on the combining powers of the magnesium and the EDTA. The action of ignoring the majority (with their unconvincing evidence that EDTA reacts with all metals in the ratio 1:1) for personal view (based on understanding of combining power) which is seen as my ‘practice’ can be understood from the mental schema that understanding and evidence based is crucial for success in education. Perhaps, the others had mental framework which attaches importance to the teachers’ knowledge as unchallenged truth and the attainment of marks as crucial hallmark of education. This view led to their practice of accepting the TA’s view (TA was to assess and give mark for the report) without questioning it.

It follows therefore, that teachers’ theory concerning development of science process skills shapes his/her decisions and actions/paths taken with students. Essentially, we know that one’s framework can change, thus we can conclude also that teacher’s experience in the classroom also continues to shape their framework concerning science process skills. Investigation into the development of science process skills should therefore consider teachers’ views with respect to the importance teachers attach to it and its associated theories. It is also necessary to deliberate on teacher variables like experience and gender that may influence such views. For example, investigation into science process skills among elementary school teachers reveals that science process skills of elementary school teachers differ significantly by gender and seniority (Aydogdu, 2015). However, Zeidan and Jayosi (2015) report insignificant gender difference in science process skills among Palestinian Secondary School Students. GES (2016) grades public schools into A, B and C categories. The grading is done based on facilities available in the schools and their academic achievements. It is therefore important to find out how the characteristics of the various school grades influence development of science process skills.

Statement of the Problem

The acquisition of science process skills by SHS students is one of the key emphases in both MoE and WAEC syllabuses, which is pursued via practical work in Biology, Physics and Chemistry (Ampiah, 2004). Notwithstanding, Ampiah showed that WAEC Chief Examiners report for physics, chemistry and biology have persistently pointed out students' weaknesses in science practical examinations over the years even though significant effort has been made to improve access, quality and frequency of the practical work through the provision of Science Resource Centres. However, analysis of Chief Examiners report of practical paper Chemistry Paper 3 from 2012 to 2016 of WAEC reveals that the poor performance stems from poor performance in the question 2 in the practical paper. The question 2 examines science process skills especially the higher ones like observation, communication of results, inferences and drawing of conclusions. The SHS (MoE, 2010) places weight on the acquisition of these higher skills under the dimension of practical and experimental skills in the chemistry teaching syllabus.

In the teaching syllabus for chemistry in SHS (MoE, 2010), three main psychological units of behaviours are identified with the following weightings: Knowledge and Understanding 30%; Application of Knowledge 40%; and Practical and Experimental Skills 30%. These are the profile dimensions of the chemistry teaching syllabus, with the third dimension, Practical and Experimental Skills composing of two distinctive skills-Practical Skills and

Experimental Skills. The syllabus restricts the Practical Skills to demonstration of manipulative skills (MoE, p.ix) which include the use of tools, machines and equipment for solving practical problems. The Experimental Skills "involve the demonstration of the inquiry processes in science and refer to skills in planning and designing experiments, observation, manipulation, classification, drawing, measurement, interpretation, recording, reporting, and conduct in the laboratory/field" (MoE, 2010 p. ix). The syllabus summarises 11 science process skills to be developed under the third dimension. These are Equipment Handling; Planning and designing of experiments; Observation; Manipulation; Classification; Drawing; Measuring; Interpretation; Recording; Reporting; and Conduct in Laboratory/Field with their clear definitions. To develop these skills, teachers are expected to involve students in project works, case studies and field studies to find solutions to problems and tasks. To what extent this is being done needs to be investigated as students' skills in these areas have been shown to be poor by the Chief Examiners' reports over the years.

Aside school based assessment, the WAEC is the main examining body for the SHS syllabus and is required to assess all the three profile dimensions in the syllabus. It seems that the Paper 3 of WAEC examination is the main assessment instrument for the third profile dimension which is on the science process skills. It is therefore, pertinent to analyse chief examiner's report on the Paper 3 over a period of five (5) years (2012 – 2016) and the nature of the questions asked in these examinations over the period.

Purpose of the Study

This study explores development of science process skills in SHS chemistry students. Though the preceding discussion has revealed the stated curricular intention of the MoE chemistry syllabus to develop science process skills in SHS chemistry education, Ampiah's (2006) analysis of specific objectives in basic school science curricula reveals a mismatch between the stated weights given to the three components of the profile dimensions and the available contents provided to develop them. The study therefore examines:

1. how teachers help students to develop science process skills captured in the curriculum.
2. how WAEC has assessed science process skills of SHS students over the past five years.
3. the opportunities and preparedness of schools to develop science process skills in students.
4. factors, which influence the development of science process skills in chemistry students at the SHS.

Research Questions

1. What science process skills have been assessed in the WAEC examinations in the past five years and where has been the emphasis?
2. What opportunities are given to students to help them develop science process skills in school?
3. What are SHS chemistry teachers' and students' perceived importance and occurrence of the development of science process skills?

4. What science process skills have SHS 3 students developed at the tail end of their school programme to enable them write the WAEC examination in practical chemistry?
5. What factors influence the development of science process skills by SHS chemistry students?

Hypotheses

Two null hypotheses (H_O) and their respective alternative hypotheses (H_A) were formulated and tested at $\alpha = 0.05$.

H_{01}: There is no significant difference between the achievement scores on the process skills assessment test of students in their different school-types.

H_{A1}: There is a significant difference between the achievement scores on the process skills assessment test of students in their different school-types.

H_{02}: There is no significant difference between males and females in terms of their achievement scores on the process skills assessment test

H_{A2}: There is a significant difference between males and females in terms of their achievement scores on the process skills assessment test

Significance of the Study

First of all, over the years, Chief Examiners' Report has revealed that students are performing poorly in the practical paper of the WAEC examination, the study however, reveals a specific area of the paper which students are struggling with. This has implication both for theory and practice. The information in the study may help practitioners and other stakeholders to reconstruct their view concerning the teaching and learning of science, which should impact on the proper manipulation and interpretation needed in practical work.

Secondly, both the MoE chemistry syllabus and WAEC give impression that practical work is the only means to develop and assess science process skills, the information in the findings will give guidance on other means to develop and assess such skills.

Thirdly, the analysis of mismatch between curricular statements and the actual contents of the curriculum will help curriculum developers to address the issue of how much content is important in the development of science process skills at the Senior High School level.

Penultimately, the information concerning students' development of science process skills will help evaluate the effectiveness and the efficiency of practical work in SHS education to develop science process skills.

Finally, the information may rekindle debate concerning the use of laboratory work in science education.

Delimitation

The study was confined to schools in the Central Region of Ghana. Central region in Ghana is opportune with different grades of schools and appeals to students from different social backgrounds and ethnicities across the length and breadth of Ghana. Aside central region being the accessible population, the region has all the three categories of Senior High Schools (SHS) identified in Ghana (GES, 2016). GES (2016) put all SHS in Ghana into three Categories – A, B and C schools based on academy performance and facilities available to the schools. Since GES assumes schools under the same category to have similar characteristics, it is inferred that locality is not the defining variables for school's characteristics; rather it is the category of the school that determines the character of the school. Central region has all the three categories, the selection of the region therefore provides good representative to generalise findings from such study. Senior High Schools in the central region can therefore accurately represent Senior High Schools in Ghana. There are 77 Senior High Schools (GES, 2016) in the 20 educational districts in the Central Region of Ghana. Though all the 77 schools offer some form of chemistry education (as part of integrated science), the population frame is restricted to only 36 schools that offer General Science as a programme where students select chemistry as an elective subject. The data is collected from 20 schools as sampled population from the 36 schools. The study collects views of all chemistry teachers in the selected schools but only the views of SHS 3 students are collected as against SHS 1 and SHS 2 students. The assumption is that SHS 3 students have spent enough years in the SHS level to develop science process skills to appreciable levels.

Limitation

The way one views and understands the nature or the essence of the process of teaching and learning (ontological assumption) influences how it is acquired or communicated (epistemological assumption), which also informs and justifies the strategies (methodological assumption) employed to understand this social phenomenon (Hitchcock & Hughes, 1995). Therefore using qualitative and quantitative approaches with different epistemological and ontological assumptions in one study appears untenable. However, aside accusation of being ‘adulterous’, it may be advantageous to stand the middle ground to decipher and carefully select the best approach from dichotomised views. The study thus stands to gain from integrating quantitative and qualitative data with different assumptions. Limitations with respect to resources, time and space imposed data limitation. For example, data collection is restricted to central region which is further circumscribed to 20 schools out of 36 schools identified to offer chemistry as an elective subject in the region. Though efforts were taken to ensure validity of the survey, respondents who still felt that they were not encouraged enough to give accurate and honest response could not have been helped like it would have been in for example, in-depth one on one interview. Those who had no opinion or unaware of the reason to select any of the option in the questionnaire did not have the opportunity to express themselves. Some respondents actually left empty spaces. Those were not coded since it was difficult to determine whether empty spaces indicated lack of opinion or evidence of respondents actually forgetting to tick any of the option. Respondents were not given opportunity to give reasons for the options they selected in the achievement test. This made it difficult to detect those who guessed answers.

Definition of Terms

Science process skills: Physical and cognitive skills used to collect data, analyse data, link up concepts and use to solve scientific problems

Observing: The use the five senses to make accurate observations.

Calculating: The ability to use formula or algorithms to solve problems.

Drawing: Drawing clearly and label specimens, objects etc.

Recording: The ability to accurately note down relevant observations, procedures or inferences for reporting.

Classifying: Grouping specimens and objects according to their common properties or characteristics.

Communicating: Ability to present pertinent and precise ideas, concepts, reports on projects/practical work undertaken.

Measurement: The use of measuring instruments and equipment for measuring, reading and making observations.

Inferring: The ability to make educated guesses or draw conclusion about an object or event based on previously gathered data or information.

Predicting: Stating the outcome of future event based on a pattern of evidence.

Interpreting: Organising data and drawing conclusion from it, explaining.

Manipulation: Skilful handling of scientific objects and tools for accomplishing specific tasks. It involves setting up laboratory apparatus, preparing specimens and other material for observation.

Experimenting: Manipulating equipment or materials to change variables for observations leading to specific inferences or conclusion

Investigating: Using established procedures and reagents to discover or infer content of an unknown sample

Hypothesising: Stating the expected outcome of an experiment

Controlling variable: Being able to identify variables that can affect experimental outcome, keeping most constant while manipulating only the independent variable

Organisation of the Thesis

The thesis is organised in five chapters. The Chapter one consists of the background to the study, the statement of the problem, the purpose and objectives of the study as well as the research questions, hypotheses, significant of the study, delimitation, limitation and includes definitions of terms and abbreviations before ending with the organisation of the study. Chapter two which reviews relevant literature to establish the rationale for the study. The chapter two consists of four parts. The part one declares the theoretical basis of the study. The part two discusses the role of science process skills in achieving scientific literacy. The part three review competing approaches to science education and the role of science process skills in each competing approach. The final part raises the central role of science process skills in the Ghanaian chemistry syllabus and develops conceptual framework to guide the study. Chapter three which discusses and justifies the research methodology used to answer the research questions and hypotheses and also raises the strength and weakness of the design. Chapter four which presents the result of the study. The chapter four presents the result under 'Basic and integrated science process skills in WASSCE Papers 2 and 3', 'opportunities given to students to develop science process skills', 'SHS chemistry teachers' and students' perceived importance and occurrence on the development of science process skills', 'Science process skills developed at the Senior High School level', 'factors influencing the development of science process skills', 'statistical differences among the type of schools students attend and their development of science process skills' and 'statistical difference between gender of students and their development of science process skills' to answer the five research questions and the two hypotheses. Chapter five gives an overview of the research questions and methodology used and summarises the key findings and their interpretations with reference to the literature. The Chapter five also discusses the implications and draws conclusions relating to the findings.

The generalizability of the findings is discussed and specific limitations of the study with respect to the internal and external validity of the research design elaborated.

CHAPTER TWO

LITERATURE REVIEW

Introduction

This study focuses on exploring how science process skills are developed among SHS chemistry students. The study examines how the school system helps students to develop science process skills captured in the curriculum. The study also examines how WAEC has assessed science process skills of SHS students over the past five years and finds out the opportunities and preparedness of schools to develop science process skills in students. The final aspect of the study is the exploration of possible factors, which influence the development of science process skills in chemistry students at the SHS level.

The chapter is organised in four parts. The first part declares the theoretical framework underpinning the study, under these subtopics: Theoretical Overview, The Anderson Model, Basic Science Process Skills, The Rachelson Model and The UNESCO Model. The second part discusses the role of science process skills to achieve scientific literacy as a goal of science education under the subtopics: Scientific Literacy, Knowledge-centred Scientific Literacy, Socio-cultural-centred scientific literacy, Wish-they-know science, Need-to-know science, Functional science, Enticed-to-know science, Have-cause-to-know science, Personal-curiosity science and Science-as-culture. The third part reviews some competing ideas on the approach to science education and the relevance of science process skills in all the different approaches espoused. This aspect is discussed under ‘Science through Education’ as against ‘Education through Science’, The model for

Education through Science, Inquiry-based versus Practice-based science education and The model for practice-based science education. The last part converges at the Ghanaian Chemistry Syllabus. This part looks at The centrality of science process skills in the Ghanaian chemistry syllabus and discusses The Model for School Science as the framework to guide the study before summarising the chapter.

Theoretical Framework

Development of science knowledge has been the result of man's curiosity and desire to understand natural phenomena and situations. Through history, man's engagement with the natural environment has led to formation of concepts, symbols and language. For instance, one observes objects in the immediate environment by the use of the senses. It is noteworthy that before what is observed is communicated, mental image of the object must be developed. That is to say, the person forms a concept of what is observed. Then the concept is communicated through symbols, gestures or language. The observer may use a general language to describe the object however, as more observations are made the general description for the object may be changed or modified. Accordingly, man throughout history has built up huge body of scientific knowledge by utilising his intellect and applying his ability for engaging in thinking, reasoning and evaluation of natural phenomena. Though it is worth sharing and celebrating this product of scientific endeavour with students, it seems more beneficial to nurture students in the process of acquiring and understanding the scientific knowledge. It is obvious that no students could have the luxury of learning all the relevant scientific knowledge during their school life but equipping them with the science process skills to search, understand and evaluate scientific knowledge is lifelong skill that will enable them to utilise relevant knowledge to solve problems that confronts them in life.

This approach resonates with the adage that ‘it is better to teach one how to fish rather that providing him/her with fish’. Additionally, it echoes Bruner’s (1962) insistence that the acquisition of the process of knowledge is better than the memorization of facts. To Bruner getting knowledge is a process, rather than being product. Though, approaching science education by nurturing students with science process skills seem more natural way of learning and depicts how scientists acquire knowledge of the world, the approach to transmit scientific products to students has dominated major curricular policies. However recently, there seems to be reorientation of curricular policies in many countries from the focus on product of scientific knowledge to science process skills. The American Association for the Advancement of Science, AAAS (1993) for instance set major goals of curricular innovations to include: (a) the development of curricular materials and science programme that are consistent with current science knowledge (b) the development of curricular materials and science programmes which provide the student with an understanding of the process of science (AAAS, 1993). It is obvious that AAAS called for change in science curriculum to reflect on current scientific understanding of how students learn science effectively and to provide students with understanding of how science works. If students are to understand the nature of science and to have understanding of science ideas or concepts, then they should have framework that link ideas together. Harlen (1999) concurs to state that in order to learn with understanding one must engage their previous experiences with new encounters. This sort of engagement allows linkages between the new experiences to previous ones for extension of ideas and concepts. This interaction of experiences permits association of ideas and concepts to a progressively wider range of related phenomena. ‘In this way the ideas developed in relation to particular phenomena (`small’ ideas) become linked to form ones that apply to a wider range of phenomena and so have more explanatory power (`big’ ideas)’ (Harlen, 1999, p. 130). If understanding involves linking up experiences, then it follows that students must experience the big ideas in order to understand. Learning with understanding in science therefore should include ‘testing the usefulness of possible explanatory ideas by using them to make predictions or to pose questions, collecting evidence to test the prediction or answer the questions and interpreting the result; in other words, using the science process skills (Harlen, 199, p. 130).

In Harlen’s conceptual development, students are given the opportunity to experience or evaluate concepts with their experience. Students’ experience offers embodied evidence through which meaningful learning is gradually developed. However, one may critique the issue of exposure and students’ experience to argue that mere exposure do not leads to meaningful learning. For example, Watson, Swain and McRobbie, 2004 cited in Osborne (2015) observed 12 -13 year olds involve in practical activities and examined the quality of their discussions surrounding practical work. They concluded that: (a) much of the work was just repetition; (b) students did not know the purpose of their activities; (c) students did not discuss conceptual link that make sense of their result and (d) students failed to seek explanation to their results or discuss the strength of their result. Abrahams and Millar (2008) also observed that almost all students' discussion of practical activities is focussed on the manual manipulation skills involved in such activities. However, the preceding flaw identified should be attributed to the deficient in teaching approach adopted not necessarily the experiential aspect. Thus the argument that exposure and student understanding alone is not always adequate to develop meaningful learning though admissible, such limitation is cured through giving students opportunity to evaluate their conclusions with alternative explanations obtained from other sources, teachers, and peers. The need for evaluative skills and critical review of knowledge for development of understanding make the role of the science process skills crucial. For example, students need to develop skills to collect relevant evidence and draw conclusions based selectively on those findings which confirm initial preconceptions and ignore contrary evidence. It is by evidence based conclusions and evaluations that help one to understand the world around. Harlen concluded that the development of scientific process skills should be a major goal of science education. Making acquisition of science process skills a major goal of science education is consensual view, however its conditions and methods of implementation needs clarification. Donnelly and Gott (1985) suggest three conditions for science process skills to have a practical theoretical role in the science curricula. They include (1) there should be clear definitions for the science process skills, (2) there should be agreed connection between the science process skills and pupils' intellectual development and (3) there should be identified methods to develop the relevant science process skills. Various models of science process skills have been developed in literature to define and explain how the science process skills are developed.

Anderson Model

Anderson (1970) defines 14 science process skills in a more like hierarchical model with observation and experimentation occupying the bottom and the top position respectively. The first eight comprising observing; measuring; using numbers; classifying; using space, time and relationship; communicating; predicting; and inferring are referred to as basic skills and the other six are the integrated skills (Akinbobola & Afolabi, 2010; Ongowo & Indoshi, 2013).

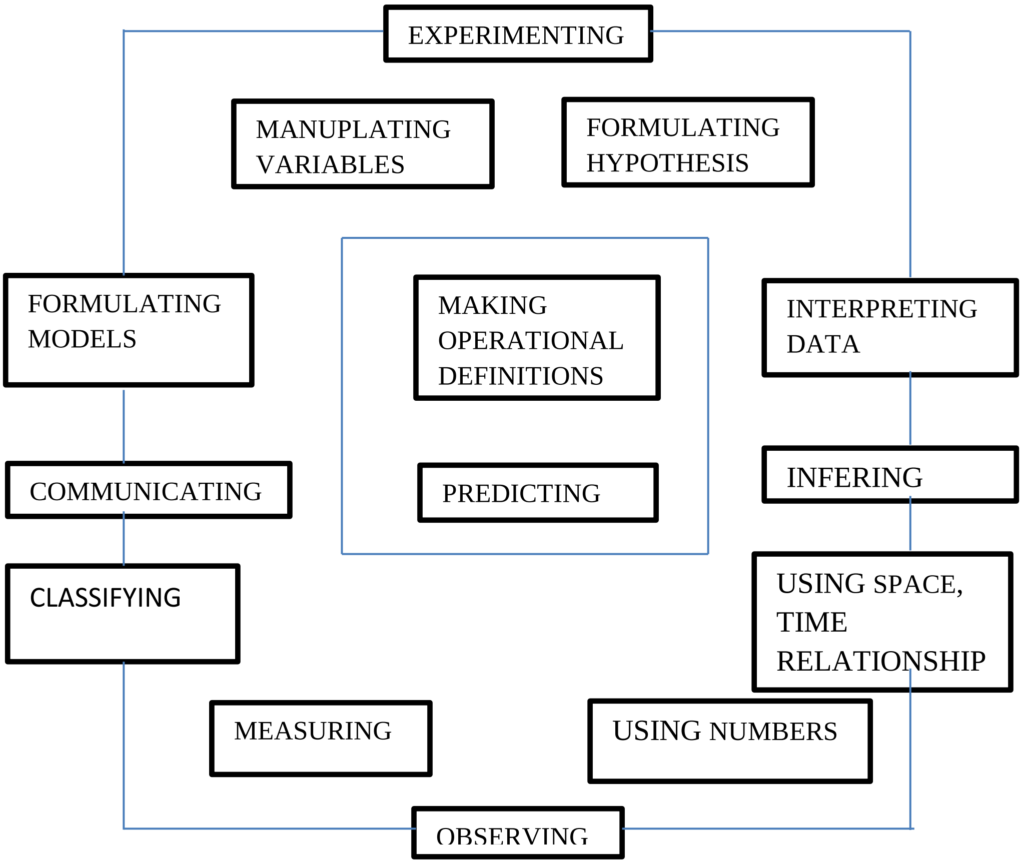


Figure 1: A Model of Science Process skills. (Anderson, 1970)

Basic Science Process Skills

This section attempts to discuss six of the basic skills in their order of increasing complexity and suggest how students could be helped to acquire and develop them. The Anderson's model starts scientific discovery or enquiry with observations. Objects and events are observed using our five senses. Observations can be made qualitatively. For example, a student can make a simple observation of the physical state of iodine as solid or the appearance as black. The students may communicate their observation of iodine simply as solid or black or may be more descriptive to say iodine is a black solid. It is important to realise that the development of the other skills depend on one's ability to make good observations. Observations are also made quantitatively. Students observe mass of a substance on an electronic balance like five grams or read the volume of a liquid in a burette as $25cm^3$. In quantitative observation number is involved thus this observation gives more precise information than what is provided by the senses. Good and productive observations must therefore contain detailed and accurate written or drawn descriptions (Seung, Choi & Pestel, 2016). By prompting students to give more detailed and elaborate descriptions of observations, they increase their understanding of the concept being studied.

However, before a teacher prompts the student to elaborate observations, what is observed must be communicated. This confirms that observations precede communication. Communication of observations must however, be clear and effective in order to portray meaning and understanding. Usually, effective communication is done by relating observations to a common referent. For instance, two students performed experiments on two different samples, sample *A* and sample *B*. The one who worked on sample *A* observed and reported white gelatinous precipitate and the other communicated white chalky precipitate on sample *B*. The two referents ‘white gelatinous precipitate’ and ‘white chalky precipitate must be familiar to the reader in order to understand and appreciate the true nature of the samples being studied. Students can communicate their observation verbally, in writing, or by drawing pictures, the use of graphs, tables, charts, maps, diagrams, and visual demonstrations. Measurement as the third basic skill adds another value to the kind of referent used. In this case, the referent must be a well-defined unit such as grams, cubic decimetre, grams per mol etc. Measurement therefore communicates observation by comparing to a defined referent unit. A measuring statement contains a number that specifies quantity and a specific named unit. The fourth skill involves sorting objects or phenomena into groups based on their observations. Classifying or grouping objects or events is a way of imposing order based on observable similarities, differences, and interrelationships. This is an important step towards a better understanding of the different objects and events in the world. Classification may be approached by simple serial ordering. In this case objects are placed into ranked order based on some property. For example, elements in the periodic table are ranked into metals, semi metals and non-metals based on the property – conduction of electricity or heat. Whereas metals are observed as good conductors of heat and electricity, the intermediate group (semi-metals) are classified neither good nor bad conductors with the lower rank being bad conductors of the same property. Furthermore, classification can be used to group objects or events into binary groups. This is usually done on the basis of whether each object has or does not have a particular property. Example is acids and bases in chemistry. The ability of these substances to either change blue litmus paper to red; or change the red litmus to blue permits such binary classification. The final classification to discuss is multistage classification. Still drawing examples from elements in the periodic table, halogens are well defined group of elements. For example, they are different from all other groups by having seven electrons on their outer shells. More observations based on their physical states separate fluorine and chlorine into halogens that are gases and bromine being liquid and the others being placed into solid category. Multistage classification as constructed using the halogens as an instance involves performing consecutive binary classifications on a set of objects and then on each of the ensuing subsets. This classification system consists of layers or stages and it is complete when each of the objects in the original set has been separated into a category by itself.

So far, four of the basic science process skills have been discussed with the attempt to place them in increasing complexity. The other two skills to be called for juridical analysis are inferences and predictions. Unlike observations which are direct evidence gathered about an object, inferences go beyond appearances to offer plausible explanations or interpretations that follow from the observations. For example, a student adds an acid into a test tube containing a colourless solution whose content is unknown. The addition of the acid generates colourless bubbles which extinguishes a flame from a burner. Plausible inferences based on the observation can only be made if one is privy to some other theoretical information beyond the observations. The observer should for example know that the bubbles indicate the presence of gas being released from the solution and the gas that extinguishes flame is carbon dioxide. Coupled with the knowledge that carbonates releases carbon dioxide on addition of acids, inferable explanation then, could be made that the ensuing observations occurred because the unknown sample contains carbonate. Accurate and precise observations of things in our environment lead to inferences, and interpretation and explanation of events around us. These process skills therefore equip us to have a better appreciation of the environment around us. It is obvious that inferences require higher processing skills than the preceding skills discussed. However, students processing skills can be sharpened to spot the difference between observations and inferences. When students' observational skills are improved through more frequent and detailed descriptions of observations, they would be able to differentiate for themselves the evidence they gather about the world as observations and the interpretations or inferences they make based on the observations. A way of doing this is by first prompting them to be detailed and descriptive in their observations. Then through diagnostic questions about their observations, they are encouraged to think about the meaning of the observations. Thinking and reflecting on inferences brings to bear that inferences depends not only on what is observed but also on previous knowledge and experiences. For example, the preceding inferences that the 'unknown colourless solution' contains carbonate could not have been made without the previous knowledge that bubbles indicate release of gas and that carbon dioxide which extinguishes flame are released from carbonates when acids are added. It follows that past experiences are critical for the interpretations of observations. It is also not uncommon to encounter different inferences made based on the same observations. Similarly, inferences may also change in view of additional observations. Thus, as students gather more supporting observations, their confidence concerning their explanatory inferences grows. For example, supposing the same gas that extinguished fire is passed through lime water to turn cloudy and another sample of known content as carbonate is allowed to go through the same processes with similar observations. The students by comparing the supporting evidence may be more confident in coming out with the correct inference.

Another use of additional observations is either to reinforce, modify or even reject previously made inferences. It shows therefore that involving students in scientific practice of using and practicing science process skills creates awareness of other areas of science. For instance, students' realisation that their earlier inferences could be reinforced, modify or rejected based on prevailing evidence introduces students to the nature of science that science is tentative. It also shows scientific value of honesty and ability to accept the truth.

The final basic skill, which is prediction concerns the ability to make educated guesses about the outcomes of future events based on present observations. Scientific prediction is also like using present observations to forecast future observations. Prediction is based on both good observations and inferences made about events. Supposing the preceding colourless solution inferred to contain carbonate was prepared from a sample taken from a particular soil then based on further observations and inferences the alkalinity of the soil or even the ability of the soil to sustain a particular plant may be predicted. Based on such prediction, decision for example could be made to alter the soil's alkalinity in order to improve and sustain the desired plant. This ability to make predictions about future events therefore allows us to successfully interact with the environment around us. Like inferences, predictions are based on observed events, past experiences and the mental models built up from past experiences. Predictions based on inferences about events offer the opportunity to test those inferences. If the prediction turns out to be correct, then greater confidence is imposed in one's ability to make inferences.

Integrated Science Process Skills

In a qualitative analysis class, the researcher engaged group of learners to make inferences in series of observations involving mixing of various solutions and reagents. The inferences made were based on behavior and characteristics of cations and anions in solutions. In the quest to create cognitive conflict to expand the learners' explanation ability, concentrated suphuric acid was added to blue copper sulphate solution. Usually to test for cations, sodium hydroxide is added to solutions and inferences from solutions that turn reddish brown upon addition of sodium hydroxide is that the test solution contains iron. In this investigation, the learners observed reddish brown from addition of concentrated sulphuric acid and blue copper sulphate solution.

Further engagement revealed that none of the test solution and the reagent contains iron. Again in chemical reactions transmutation of elements are not possible. Further inferences based on the same observation of reddish brown colour appearing from the test solution and reagent in view of various theories brought the explanation that the concentrated acid might have displaced copper metal which also has appearance of brown from solution. This skill of explaining employs higher intellectual processing by combining theories to make series of inferences based on observable event. This is called interpreting skill. Interpreting skill belong to higher science process skills called integrated science process skills.

The preceding discussion reveals that the basic science process skills apply specifically to foundational cognitive functioning (Rambuda and Fraser 2004). Basic science process skills represent the foundation of scientific reasoning learners are required to master more advanced integrated science process skills (Brotherton & Preece, 1995). Like all integrated science process skills, the interpreting skill relied on basic science process skills like observations and inferences, however integrated science skills offer explanations and solutions to scientific problems. Rambuda and Fraser (2004) assert that integrated science process skills are the immediate skills required in problem solving or doing science experiments. Implication of the term ‘integrated’ is that learners are employed to combine basic science process skills for greater expertise and flexibility to design and investigate phenomena. The integrated skills include controlling variables, defining operationally, formulating hypotheses, interpreting data, experimenting, and formulating models.

Rachelson Model

Though the discussion of the six basic skills begun by asserting their possible ordered increasing complexity, it has been shown for instance that observations inform inferences and inferences inform further observations.

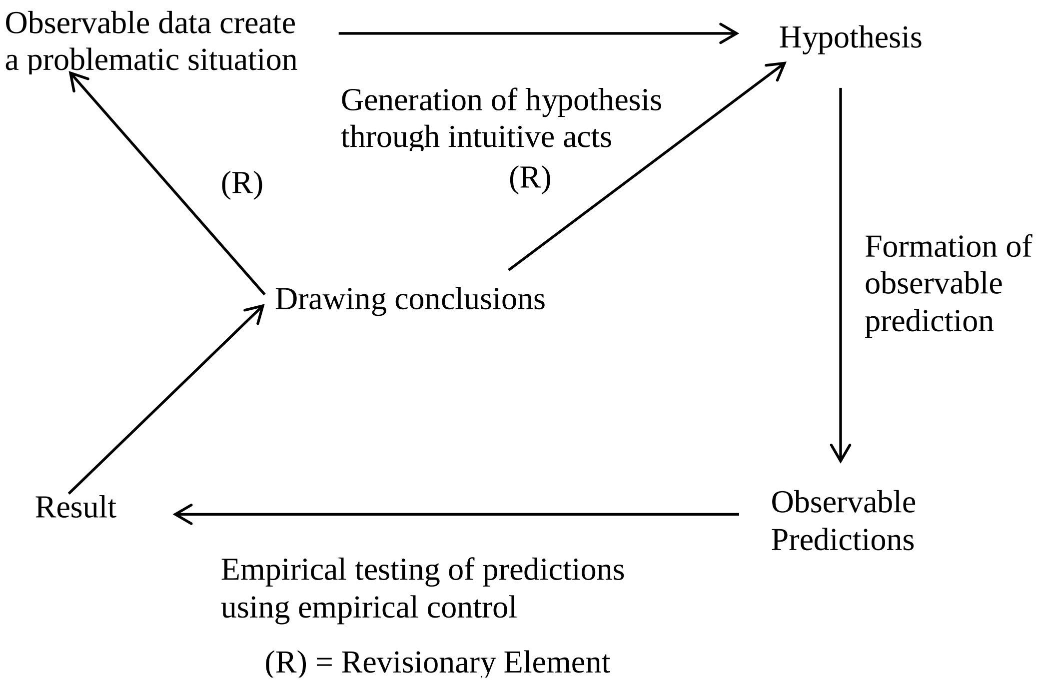


Figure 2: Process of Scientific Inquiry (Rachelson, 1977)

The scientific process used by scientists to ask and answer questions therefore may proceed by integrating together the science process skills not necessarily in linear manner but rather in a cyclic way. This cyclic model seems to resonate with Rachelson (1977) model of scientific enquiry (figure 2). Rachelson introduces the concept of revisionary element as a self-correcting mechanism. The revisionary element is critical and unique characteristic of scientific inquiries which gives room for repeating scientific enquiry process. The revisionary element suggests that new understanding and evidence may lead to re-examination of primary data or hypothesis. A test case is the re-interpretation of fossils from the Burgess Shale (Gould, 1989). Gould tells a story of how sixty years after Charles Walcott's conclusion of the fossils based on the theory of evolution and diversity of organism were re-examined and interpreted differently by different group of scientists.

UNESCO Model

Though Rachelson's model shows the cyclic view of scientific enquiry, it fails to depict fully the kind of interaction demonstrated in the preceding discussion. For example, it was demonstrated that observations inform inferences and inferences inform further observations. This sort of interaction among the components of enquiry seems absent in the Rachelson's model. However, UNESCO source book for science teaching (Harlen & Elstgeest, 1992) gives a model of science process skills in more interacting way (Figure 3). Though the UNESCO model introduces interaction among the science process skills, it includes manipulative skills which have attracted recent criticism. For example, overemphasis on the manipulative skills is said to prevent students from engaging in useful discussion that brings about meaningful learning (Abrahams & Millar, 2008).

Figure 3: Process skills as part of a whole called Scientific Investigation (Harlen & Elstgeest, 1992)

It is also argued that the manipulative skills 'developed with the scientific instrumentation available in the standard school laboratory are not, given the significant difference in instrumentation, necessarily the same as needed in a university laboratory or the workplace' (Osborne, 2015, p. 20). However, the motivation and interest which students derived from manipulating materials and equipment during the learning process cannot be over-ruled.

In summary, students could be aided to successfully integrate the science process skills with classroom lessons and field investigations. This approach is not only likely to make the learning experiences richer and more meaningful for students but also offers students the acquisition of science process skills as well as science content with possible inculcation of some scientific attitudes. This approach not only prepares future scientists but also citizens “who need `scientific literacy’ in order to live in a world where science impinges on most aspects of personal, social and global life’ (Harlen,1999, p. 131).

Scientific Literacy

Recently, there has been emphasis on science education for all in an attempt to make citizens scientifically literate. The term scientific literacy was introduced into science education in the late 1950s (Hurd, 1958; McCurdy, 1958; Fund, 1958) and espoused the need to teach science to all students irrespective of their chosen career path (Bybee & Deboer, 1994). Brown, Reveles and Kelly (2005), Holbrook and Rannikmae (2007) and others have provided common rationale for studying science subjects in school toward the achievement of scientific literacy in the recent times. Brown *et al* for example raised two central perspectives that emerge out of discussion of scientific literacy. According to them, the first perspective is knowledge centred.

Knowledge-centred scientific literacy

This knowledge centred approach to viewing scientific literacy places emphasis on scientific content which include development of scientific knowledge, practices, and habits of mind. This view also involves ways of using knowledge as: (1) citizens, for example engaging in debate concerning genetic modified food or (2) individuals acquiring literacy for some extrinsic purposes like passing high stake examinations. However, there is the danger that such knowledge based approach to scientific literacy may lead to an over-emphasis on content. Most content in the curriculum is presented in reductive form and is usually abstract and separated from the daily experience of students. Therefore over-emphasis on content may not only overshadow acquisition of educational goals like applying learnt concept to solve problems and but also has the tendency to prevent the achievement of multi-dimensional levels of scientific literacy (Bybee, 1997) that promote effective functioning within society. This line of argument is not to downplay the importance of scientific concepts. People need certain knowledge and understanding of scientific concepts, processes and skills in order to take personal decision, partake in civic and cultural activities, and to engage in economic productivity. According to Brown et al (2005) knowledge- centred scientific literacy becomes strengthened and sustained when it considers broad and general educational aim which includes solving personal problems and engaging in social and economic issues. The knowledge-centred scientific literacy unlike tradition view of science with usual overemphasis on concepts and terminology, shifts emphasis to broaden the traditional focus to include cognitive abilities, reasoning, habits of mind, unifying concepts, and communication (AAAS, 1993; NRC, 1996). The inclusion of the development of science process skills implies that students will be equipped to use these abilities and emotional dispositions to construct science understanding through linking up of small ideas and experiences to the big ideas of science (Harlen 1999). Students engaging in knowledge-centred scientific literacy will also be supported to develop skills of communications to inform others about scientific ideas in a more persuading way for informed decisions (Hand, Lawrence & Yore, 1999). Hand *et al* view this perspective of scientific literacy as a means of incorporating 'the interdependent dimensions of the nature of science and scientific inquiry, reasoning and epistemological beliefs in the construction, dissemination and application of science knowledge' (p. 1021). This interdependency is the recognition that everyday life activities are replete with complex science and technology issues. To combat the myriad of science and technology issues in everyday events require the competency in (a) identifying the specific scientific issue being confronted with, (b) by offering plausible explanation through (c) the use of scientific evidence (Bybee & McCrae, 2011). However, the required competency only becomes possible through science process skills and habit of mind that utilises the acquired scientific knowledge, the nature of scientific enterprise and scientific attitude efficiently and effectively. This view is supported by Pedretti (2005) who asserts that the boundaries of science, technology, society and environments are becoming increasingly difficult to distinguish. Everyday society is confronted with concerns such as genetic engineering, water and waste management, environmental degradation and other socio-scientific issues. Science process skills are needed to mitigate these everyday issues

(Aydogdu, 2015). The Framework for Programme for International Student Assessment (PISA), 2006 (Bybee & McCrae, 2011) depicts this graphically in Figure 4.

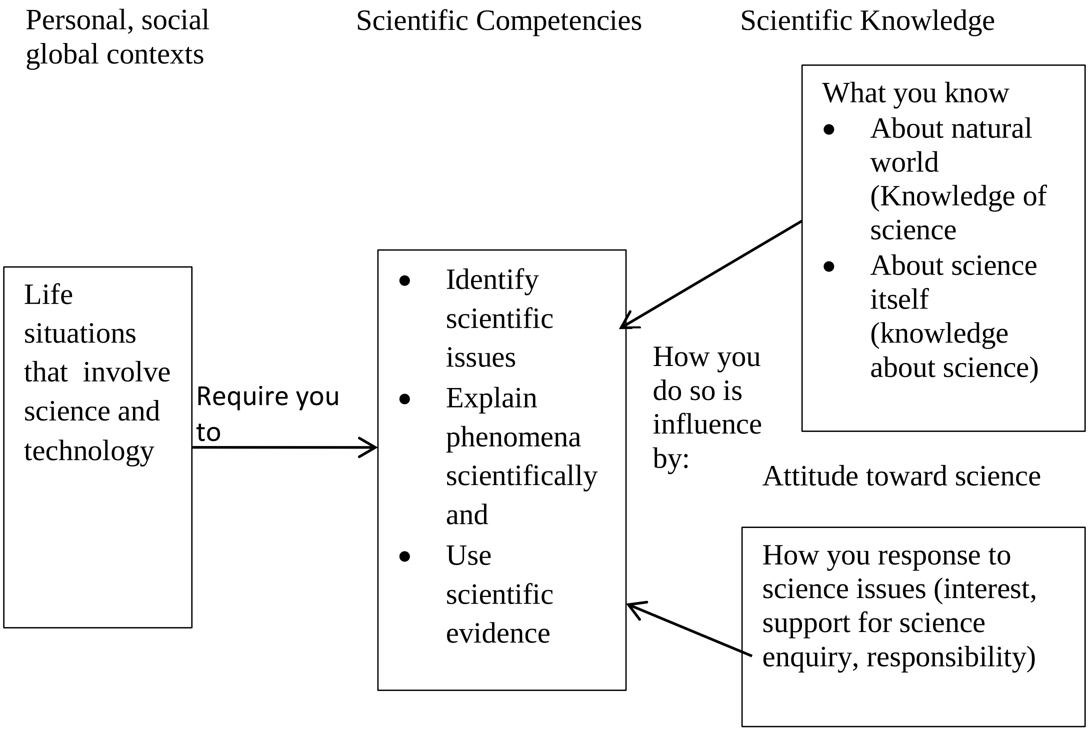


Figure 4: Framework for PISA 2006 Science Assessment (Bybee & McCrae, 2011)

Cobern, Gibson and Underwood (1995) agree with the framework for PISA 2006 with the view that scientific literacy should not inundate students with just knowledge but rather equip them with knowledge and science process skills to understand everyday scientific problems and offer solutions. They argue that students have the habit of mind and the skills of a scientifically literate person only when they possess the know how to apply basic scientific concepts to solve everyday scientific challenges. This state of students' development can be achieved if they are given opportunities to develop their science process skill to identify situations where science literacy and competency would be an advantage. Explicitly, the curriculum and the pedagogical approach must provide such opportunities to students.

Hurd (1998) also highlighted this idea that the curriculum must enrich students' experience to develop science process skills when he linked academic science with the life world of the student. Hurd called for the facilitation of this purpose through 'a lived curriculum and a range of thinking skills related to the proper utilization of science/technology information' (p. 407). According to Hurd, the extent of students' acquisition of cognitive competencies to face the challenges of life situations determines their level of scientific literacy. This perspective of scientific literacy focuses on the 'utilization of scientific knowledge for the benefit of individuals, the common good or social progress' (p. 409). Development of cognitive skills and depositions among students equip them to understand the nature of science. The effect is a scientifically literate person who distinguishes and recognizes important aspect about science including 'expertise, dogma, pseudoscience, and epistemic limitations, the temporal nature of knowledge, effective argumentation, and relationships among claims, evidence, and warrants' (Hand, Lawrence & Yore, 1999, p. 1022).

Scientific literacy with science processing skills offers positive dispositions towards participation in public debate on scientific issues. A scientific literate person must be equipped with the requisite knowledge, willingness and habit of mind to engage in relevant and broad social issues. For example, students should be able to use relevant data and evidence to ask questions on policy concerning for instance, water and sanitation. Students should be involved in debate as to whether parliament should approve introduction of genetic modified crops in the nation using scientific means rather than embracing a particular opinion group without scientific scrutiny. This assertion resonates with the view that secondary school students should be oriented to understand that science literacy promotes lifelong learning. And that secondary education should not engage students with activities focussed on mere acquisition of school-based, examination-focused information (Kyle, Linn, Bitner, Michener & Perry, 1991). The National Science Education Standards (NRC) agrees that science literacy should focus on preparing students to (a) engage intelligently in public discourse and debate (b) construct explanations of natural phenomena (c) test these explanations in many different ways and communicate their ideas to others and (d) develop a rich knowledge of science (NRC, 1996). Achieving the NRC lists demands more than familiarity with the procedural and conceptual knowledge. It is imperative that development of cognitive skills and deposition as ‘a capacity and willingness to contribute to public discussion about the application of scientific principles to social issues’ (Hand *et al.*, 1999, p. 11022) is needed.

Social issues usually are multi-facet, it implies therefore that expert knowledge from different science fields are required for fully and better understanding of these issues. It follows therefore that science literacy should mean broad-based community understanding of the procedures and claims of science (Bybee, 1995, Cobern *et al.*, 1995). Bybee (1995) calls for scientific literacy beyond the acquisition of relevant vocabulary, conceptual schemes and procedural methods to include multidimensional perspectives about science and its relationship to other fields of study. This multidimensional perspective about science and its relationship to other field of study transcends teaching students to have knowledge in for example (a) the nature and relationships between science as inquiry and technology as design, (b) the history of science ideas, and (c) the role of science and technology in personal life and society. It requires science process skills to understand the relationship among the various fields. In Ghana, for instance, students who select science as course of study at the SHS level, aside, offering Physics, Biology, and Chemistry as subjects also do mathematics, English and Social studies as compulsory subjects. Though, their combinations of subjects concur with the American Association for the Advancement of Science, AAAS (1990) contention that science literacy should embrace other domains, such as mathematics and social sciences, if students do not develop science process skills they may not understand the relationship among them to develop the required scientific literacy. Science process skills equip students to examine critically the common features and differences among the various fields and their unique way to understand social issues. Students with developed science process skills will have the evaluative skills to assess various solutions derived from different expert perspectives to conclude on consensual solution which is culturally acceptable to the community. Hand et al indicate that this view of science literacy provides effective science teaching and learning that incorporates understandings of the nature of science and inquiry which combines the roles and functions of reasoning and interpretative beliefs. Hurd (1998) add further that the curriculum that supports scientific literacy must be culturally based in order to harmonize with the contemporary ethos and practice of science. Hurd seems to call for scientific literacy that resonant with the second perspective which is socio-cultural-centred perspective.

Socio-cultural-centred scientific literacy

The second perspective situates scientific literacy in the need of meeting everyday life challenges. The socio-cultural-centred perspective is different from the knowledge-centred in a way by its usual contextualisation of relevant literacy to particular tasks at hand. (Kelly & Brown, 2003; Roth & Lee, 2002). In tackling any social tasks, knowledge and science process skills are crucial, however the modes of interaction and socio-historical contexts brought into play in the construction of the literacy event cannot be overemphasised.

Anecdotal recall of discourse with a year 8 student (a 12 year old student in the city of London) throws some light on the preceding point. After realising that the student's explanation to why the flame of candle goes out when blown during celebrations was based on 'the carbon dioxide in the blown air from the mouth', I asked why was it that the flame in firewood burns better when it is blown. Not only did she doubt but stated also that none of her mates will believe when they hear that 'firewood could burn better with blowing. This experience of blowing air from the mouth to rekindle firewood is rather common to most Ghanaian students. The implication is that the social, cultural and historical milieu of students constructs unique knowledge. Since new knowledge emanate from old knowledge, the mode of interaction needed to construct meaning from the social task of why flame of candle goes out with blowing air from the mouth should be different from the preceding cultures. Whereas, the Ghanaian student's explanation based on the carbon dioxide could be challenged simply by causing reflection on the firewood episode, the London student need to experience the episode in order to bring about conflict capable of challenging her ingrained perception of the task. Thus both knowledge and the means through which it is constructed are socially and culturally situated. Roth and Lee argue that Knowledge-centred literacy is abstracted from reality since it lacks the dimensions of social view of knowledge and situated use of expertise. Still drawing inspiration from the episode of the 12 year old London city student, the carbon dioxide explanation is an effect of concept led exposition which is characteristic feature of knowledge-centred literacy where concepts are taught follow by how the concept taught is applied in real life situations. So here, this intelligent London city student is armed with knowledge that carbon dioxide is used to extinguish fire and that human beings breath in oxygen and breath out carbon dioxide. At the personal and individual level, the blown air from the mouth contains a lot of carbon dioxide which has the property of extinguishing fire. Therefore, at the individual level the situated explanation that ‘the carbon dioxide from the mouth is responsible for quenching the candle flame’ sounds logical and general. However, in the community of other peers, the explanation may be questioned and challenged based on different experience and evidence. For example, aside the firewood episode, if blown air is really full of carbon dioxide, why do we use blown air for mouth to mouth respiration to resuscitate in situations of limited oxygen availability. The effect of contrasting evidence creates the search for more general explanation. Thus scientific knowledge is not created at the personal level but rather constructed among community of members. Roth and Lee (2002) accuse knowledge centred perspective as being overly individualistic views of scientific literacy which focus attention on the ways students acquire knowledge without considering how they construct knowledge through social interaction as members of communities. It is however, inferable that whereas knowledge centred view proposes the acquisition of knowledge as preparation to engage in social events, the socio-cultural-centred perspective proposes to engage students in social activities that employ knowledge (Brown *et al*, 2005). One of challenges with the socio-cultural view seems to bother on the nature of knowledge needed to engage students within a particular cultural and social milieu to negotiate relevant social tasks.

This challenge tends to question relevancy of standards and globalised science education (Aikenhead, 2008). Aikenhead concur with Guo (2007) and Gray (1999) who assert that importation of science curricula and pedagogy developed within one cultural milieu into other cultural milieu usually fails to succeed. Aikenhead gave examples of such importation from America to Korea and Canada. The Korean case involve the attempt to import a 1970s American inquiry teaching method into Korea which according to Lee, Adams and Cornbleth (1988), led to dysfunctional classrooms. The reasons for the failure were attributed to political realities revolving around American foreign policy, intellectual ethnocentrism, cultural differences between nations, and the self-interests of a few Korean educators in positions of authority (Aikenhead, 2008). The Canadian example concerns their rejection of Standards and Project 2061 citing the fact that such programmes were developed by Americans for Americans as reason for the rejection. Aikenhead argue that although the nations of Canada and the United States are the closest of friends, their history, social institutions, and culture are not similar. The result is that Canada developed its own national science curriculum framework in the 1990s which focuses on Canadian culture. The import of Aikenhead's argument seems to suggest that rather than countries adopting globally agreed concepts and standards to be transmitted to students, the primary goal of school science must equip students to identify their unique socio-cultural issues, understand them through critical evaluations and offer solutions to the challenges that emanate from those socio-cultural issues. The paradox however, is the medium through which the critical evaluation is applied to understand the unique socio-cultural issues. Is it possible for a country to ignore the vast accumulation of knowledge which Aikenhead refers to as Euro-American science and create its unique scientific knowledge to understand its local interest? Aikenhead concede that following such line is so huge path to pursue and advise that the general strategy is 'balancing local interests with Euro-American science'. A test case for the proposed strategy is community-based, culturally sensitive, school science teaching materials developed in Canada for First Nations (Indian) students in the province of Saskatchewan (Aikenhead, 2001). Aikenhead called the strategy an overt cross-cultural approach to school science where teaching materials are completely reformulated into a cross-cultural perspective to make it culturally sensitive to the locals while retaining relevant Euro-American elements. The curriculum contains both local indigenous ways of knowing nature and globalised academic concepts. Here, students are taught how to use relevant scientific concepts and technique to understand local issues in a need to know basis. The approach avoids accumulation of concepts which is usually acquired through memorisation and its associated game which Aikenhead refers to as 'playing Fatima's rule'. This socio-cultural approach to learning and teaching, according to Aikenhead, produces shift in outcome from "knowing that" to "knowing how to learn relevant content" (Aikenhead, 2008, p.8). This shift in school science policy resonates with school science curricula goal refers to as knowledge economy (Guo, 2007; Bybee & Fuchs, 2006). Powell and Snellman (2004) define 'knowledge economy as production and services based on knowledge-intensive activities that contribute to an accelerated pace of technical and scientific advance…' (p. 199). Knowledge economy goal in science education calls for the intelligent use of relevant scientific knowledge to generate values that promote advancement of society rather than generation of just knowledge. Powell and Snellman indicate that 'the key component of a knowledge economy is a greater reliance on intellectual capabilities than on physical inputs or natural resources' (p. 199). It is the need for the development of intellectual capabilities that Bybee and Fuchs (2006) warn the US science education community to recognise the contemporary situation of losing its competitive edge in the global economy. Their prescribed solution was the need 'to give our students the skills that they will need to prosper in a time of unprecedented global economic competition (p. 350). This shift from acquisition of knowledge to building of intellectual capacity stresses the need to develop science process skills using relevant and useful context. Two main issues that emerge from this approach to science education are (1) what scientific knowledge count as educational relevance in school science and (2) who decides what is relevant. Seven different kinds of relevant knowledge are found in literature including : (1) Wish-they-know science (2) Need-to-know science (3) Functional science (4) Enticed-to-know science (5) Have-cause-to-know science (6) Personal-curiosity science and (7) Science-as-culture.

Wish-they-know science

The wish-they-know category of relevant science knowledge is usually decided by ‘academic scientists, education officials, and many science teachers… who invariably confirm the conventional curriculum’s canonical science content’ (Aikenhead, 2008, p. 19). Aikenhead called this relevant knowledge conventional Euro-American science curriculum. The wish-they-know science embraces the subject matter of scientific disciplines and the subject matter’s psychological equivalent for high school students (Deng, 2007). The latter is the curricular content of school science. The content facilitates teaching and learning and is usually driven by social and political needs (Grossman & Stodolsky, 1994). The school science curriculum has unique histories, pedagogical traditions, and status (Grossman & Stodolsky, 1994) that frame classroom teachers’ practice and perspectives and their interpretation and response to educational policies (Grossman & Stodolsky, 1995). It implies that school science content relate to the academic discipline such that the scientific discipline provides the frame of reference that defines and delineates what classroom teachers need to know about the school science content they are supposed to teach (Deng, 2007). The scientific discipline determines teachers’ subject matter in terms of three variables including content knowledge (CoK), pedagogical content knowledge (PCK), and curricular knowledge (CuK) (Shulman 1986).

The ability of the teacher to present the curricular content to the student in a logical and meaningful way to a large extent therefore depends on the scientific discipline and the curricular content. Students make meaning out of received information when they see patterns in such curricular information and can also relate them to their experience. To the expert, the scientific content in the school science curriculum though consist of complex theories, laws, models and others, these complex system are related and can be conceptualised into frameworks. It is obvious that experts possess science process skills that help them to see the patterns in the wish-they-know knowledge and the need to transmit to students. However, the novice students who lack science process skills may view the content as numerous, dreadful, unrelated, abstract and disconnected to their everyday needs. It is a fact that cannot be denied, that learning is a natural activity to every human being. People learn as they engage in concrete and relevant everyday cultural activities. It follows that for students' science learning to be facilitated; teachers should employ their content knowledge, PCK and curricular content knowledge to help them see patterns and relevance in the school science content. Failure to assist students to develop framework that perceives relevance and connectivity of science content effect very little meaningful learning. Students' learning is found to be constrained not only by the cognitive ability and previous knowledge of the students but also on the students' perception of the science content and the teaching and the learning context set to develop science concepts. Taber's (2005) assertion that 'science is a highly conceptual business, and learning science is about building – and developing – interconnecting frameworks of scientific concepts' is only useful if the system help students to share such perception. To change students' perception of the science content in order to help them have disposition to apply their cognitive capacity alone seems to be an Herculean job in most cases than not. This situation leads to the search for specific content knowledge students need to know which also has the feature to fill the gap of relevance. The result of such search gave birth to the concept of need-to-know science.

Need-to-know science

The general public including students are usually faced with real-life problems and are confronted to make science and technologically related decisions. Countries of different cultures also are faced with different cultural problems. The irony even is, within nations, student population becomes more culturally and linguistically diverse (Lee, 2001). Research evidence indicates that conventional notions of science content, learning, teaching, and assessment have a challenge on students from culturally and linguistically diverse background (Lee, 1999). This evidence interrogate 'what counts as science, what should be taught, how science is taught, and how student learning can be assessed in valid and fair ways' (Lee, 2001, p. 499). Approaching science education by selecting relevant content knowledge on a need-to-know basis in a common context to these students of diverse interest not only addresses the issue of equity, but also provides mediational tool to construct meaningful learning. The approach of engaging learning of relevant concepts in a common and familiar context embodies learning.

Embodied learning embraces cognition, perception, cultural tool and action in the learning process (Hill & Smith, 2005). For example, teaching the concept of alcohol in an integrated course to a non-science class, decision was taken to contextualise the topic in production of a local gin called

‘Akpeteshie’. A student whose parents were into the business of producing Akpeteshie was identified and referred to as a ‘Vising Professor Agbezo’. Professor Agbezo went to a different class to narrate how the gin is made. All his narrations were accompanied with samples of distilled gin, mixture of sugar cane syrup with and without yeast and sugar cane. The samples and the narrations became an embodied structure for students’ interactions and meaning making. Students’ questions and discussions were carefully directed to discuss relevant concepts in the curriculum. For example, concepts like mixture and method of separation (simple distillation) were re-echoed. Some cultural beliefs concerning alcohols were also addressed before tackling abstract aspects like structures of alcohols and their reactions. For instance, the concepts of oxidation and evaporation were used to create meaning for the beliefs that old Akpeteshie ‘bites’ (irritating effect of drinking alcoholic beverage with high alcohol content) better than new ones and that bottled Akpeteshie when stored on concrete surfaces tend to bites less. In the former belief, it was established that the trapped air in the bottled drink oxidises some of the ethanol in the drink into ethanoic acid. The ethanoic acid is more irritating than ethanol. Thus the produced ethanoic acid mixes with the drink to give ‘more bites’. The changes in temperature of the floor in the case of the latter however evaporate the alcohol preferentially to the water in the mixture. This makes the drink more diluted with respect to alcohol content making the drink ‘bite less’.

The approach was highly motivational and students’ satisfactions were so obvious in the way they interacted and asked questions. De Jong (2008) however states that chemical education reform is eminent in many countries due to growing dissatisfaction with the position of many chemistry curricula. De Jong not only accuses the chemistry curricula of being ‘quite isolated from students’ personal interest, from current society and technology issues’ but also faults them of lacking ideas from modern chemistry. De Jong also prescribes contextualisation of relevant content in need-to-know basis as one of the remedial measures. However, De Jong raises the issue of meaningful context. Four domains are discussed as meaningful and relevant.

These include the personal domain. It is believed that selecting contexts from personal domain contribute to the personal development of students by connecting chemistry with their personal lives. De Jong recommends everyday life issues like personal health care and sees the need to relate poisonous effects of substances on the body to biochemistry processes, and the context of personal body lotions linked to the chemical characteristics of the components of the liquids they contain. The second domain relates to social and society. The social and society domain is claimed to be important in the sense that such an approach prepares students for their roles as responsible citizens. Social issues like acid rain and climate changes have daring environmental impact on society. Preparing students to clarify the role of chemistry in these important social phenomena is a worthy educational goal. The third aspect is the professional practice domain. The rationale for including the professional domain is the fact that some of the students may eventually end up in science related careers. It therefore pays to inform students on the issues relating to their future role as professionals in either public or private areas. De Jong suggests that the practice of chemical engineers can be linked with small scale designing and testing of industrial processes. For instance, small scale production of glues or polymers, and the practice of chemical analysts are related to school science topics like investigating the quality of water, food, or medicines. Students aspiring to work in these areas are likely to be motivated to learn the relevant knowledge pertaining to these contexts. The final domain relate to science and technology. Selecting contexts from scientific and technology domain is an opportunity to create students' awareness of the enterprise of science and technology. De Jong claims issues like scientific ways of handling and reasoning enhances scientific and technological literacy of students. For instance, teaching and learning of the concept of acid and base in school science involve the historical development of three models- models of Arrhenius, Brønsted, and Lewis. The shift in the model of acid and base can be related to the context of paradigm shifts in meaning of models and theories in chemistry. It is worth noting that particular contexts may overlap into different domains. Issues like food poisoning though may bother on personal domain, also concerns social and society as a domain. Recalling that the third domain in the preceding discussion involves professional practice domain, research on people mainly in science related occupations reveals another kind of relevance called functional science. Systematic research has produced a wealth of general and specific outcomes of relevance science knowledge. The functional knowledge is not normally found in school science but found in science-based occupations and everyday events.

Functional science

Ryder (2001) examines published case studies involving individuals working in science related areas. These individuals though are not professional scientists, do use/interact with scientific knowledge and/or professional scientists in their daily businesses. For example, electrical workers use electricity and its related concepts and media people may research scientific findings and/or interact with professional scientist concerning their work and communicate the findings to general public, usually based on their construct of the findings. The review revealed four (4) main contexts with unique relevant knowledge contents.

The examination shows that there are contexts in which the relevant subject matter knowledge is contained in school science curriculum. In this case, Ryder reports that the principles of gene inheritance and gene expression which are taught in school science are prominent in the study. One of such case study is Richards, Hallowel, Green, Murton and Statham (1995) who identified functional science in the areas of school science genetics involving the chromosomes and their associated concepts responsible for the pattern of inheritance. They argue that such school science concepts should be used to counsel people living with hereditary breast and ovarian cancer. Usually people without symptoms of such disease may be carriers whose progeny may show up with the disease. Since people do not understand the interplay of recessive genes and recessive inheritance, they become confused when such issues are raised during counselling (Richards, 1996). The implication is that when such functional science is taught to students with understanding rather than just memorisation, the general public will be better prepared to cope with genetic diseases. Other contexts were found to have relevant subject matter knowledge which is beyond the scope of school science.

In some of the case studies, the subject matter involved was over advanced or too specialised. Ryder gave two examples to indicate situation where relevant knowledge is too advanced or too specialised. For example, a case involved community advisory forum set up to review alternatives for local waste management was cited (Petts, 1997). The relevant knowledge drawn upon involved the health effect of dioxins and dioxin formation mechanism. This subject matter is considered both too specialised and too advanced. The other concerns the interplay of the risk of Coronary Heart Disease (CHD), high blood cholesterol level, inheritance and resistant to dietary alterations (Lambert & Rose, 1996). The expert conclusion was that though such relevant knowledge may be coped with at the school science level, it is nevertheless highly specialised information which should be communicated at the point of contact with the healthcare professional. It is also argue that even if students are taught such specialised knowledge, they are unlikely to utilise such knowledge. There are other contexts where the relevant subject matter knowledge is unavailable.

There are some health issues that confront society with the relevant subject knowledge to face those contexts still the subject of expert debate. Layton, Jenkins, MacGil and Davey (1993) discuss the case of Down’s syndrome. They assert that the chromosomal cause of Down's syndrome is highly complex and the hormonal and environmental factors that cause the defect are still subject of scientific debate. It is still a puzzle to many as why one out of healthy children from a particular couple, may be Down’s child. This case, according to Ryder (2001is an example of the limitations of science in understanding everyday contexts.

There are yet other contexts in which relevant subject matter knowledge contradict concepts in school science. Caillot and Nguyen-Xuan (1995) describe concepts among unskilled manual workers and office staff in the electric and electronics industry for instance, as functional understanding of electric phenomena. However, such understandings are considered misconception in the face of school science. In summary Ryder's review reveals that the relevant knowledge needed in science related job is context specific and most of the time different from school science. Similarly, Duggan and Gott (2002) explored the relevance of science for people in science-based industries and for public interaction with science in their mundane activities. Their quest was to answer the question 'What sort of science education do we really need?' They scrutinised available relevant documents and conducted semi-structured interviews 'in a small sample of industries, in community action groups and in personal decision making' (p. 661). Their methodological approach to the study was informed by their earlier work (Gott & Duggan 1995). 'The model that informed the study was derived from earlier research into the cognitive processes involved in problem solving in the performance of practical tasks in science education' (Gott and Duggan, 1995, p. 664). Gott and Duggan seem to separate the manipulative aspect of science process skills and referred to as skills while consider the enquiry tactic and the cognitive processes aspect as procedure knowledge. The separation was informed by the observation that students usually succeed to use manipulative skills to collect data but fail to discuss and use the collected data to make decisions. Similar observations were made by Watson, Swain and McRobbie (2004) who led to conclusion that: (a) much of the work was just repetition of manipulative skills; (b) students did not know the purpose of their activities; (c) students did not discuss conceptual link that make sense of their result and (d) students failed to seek explanation to their results or discuss the strength of their result. Such observations compel rethinking of what counts as authentic science education. Thus, Duggan and Gott' (2002) search for authentic science education is justified. However, Duggan and Gott undertook their quest with a model that effective problem solving involves an interaction of relevant concept knowledge and procedural understanding, though they admit that procedure knowledge is underpinned by skills. Their findings support the preceding view that the relevant knowledge required in science related jobs are highly contextualised and therefore suggest functional science education that builds on students' procedural understanding. This approach is believed to prepare students to face industrial challenges and effectively interact with everyday scientific issues. Cognitive skills like evaluating evidence, validity and reliability and critical examination of scientific claims are generic skills needed to build the capacity of students to engage in functional science rather than wish-they-know science is the required authentic science education (Aikenhead, 2008).

Enticed-to-know science

The print media, social media and internet sites usually draw upon sensational and controversial relevant science knowledge. Their approach motivates and attracts large readers and viewers. The effect is that the general public form their own concepts concerning these fancy relevant sciences referred to as entice-to-know science. Millar and Wynne (1988) argue that in most cases the entice-to-know conception of the general public cannot help to successfully interpret and cope with everyday science and technology issues. They called for the need to discuss this relevant knowledge in school science. The public interaction with science goes beyond the media sensation of science issues to real life issues that confront them on daily basis. Experts' interaction with the general public on real life issues, and the problems the public encounters when dealing with these experts on science related topics also leads to expert advocacy for such relevant knowledge to be taught in schools. This relevant knowledge is have-cause-to-know science.

Have-cause-to-know science

Aikenhead (2008) asserts that have-cause-to-know approach to school science assumes that experts are better placed than academic university scientists to decide what school science knowledge is worth knowing in today's changing scientific and technological world. Law (2002) interviewed experts working in Hong Kong's democratic institutions involving the legislature, a government planning department, and a civilian environmental advocacy group. The objective of the study was to explore the qualities a person require to function effectively in everyday coping, social decision making, working in technological industrial enterprises, and extending the frontiers of science and technology. Law asserts that the public's have-cause-to-know science for decision making was very similar to that required for everyday coping and that socio-scientific decision making drew upon complex skills to critically evaluate information and potential solutions. The conclusion made was that contrary to much conventional wisdom and the practice of specifying lists of wish-they-know relevant science content as the key elements of a science curriculum, habits of mind, attitudes, and values were the prominent issues recommended by expert.

Personal-curiosity science

According to Aikenhead (2004), for personal-curiosity science, students themselves are the decision makers concerning what pass as relevant knowledge to be included in school science. The topics selected for school science usually tend to meet the interest and curiosity of students and thus expressing their cultural self-identities (Brickhouse, 2001; Carlone, 2004; Häussler & Hoffmann, 2000; Reiss, 2000). This sort of relevance emerges due to the findings that the wish-they-know science usually (1) fails to meet the personal aspirations of students and that (2) students will only be engaged in meaningful learning way when their personal values and cultural self-identities are strengthened. Sjøberg (2003) reports on an extensive international study of personal-curiosity science, the Relevance of Science Education (ROSE) project. This project was based on survey conducted in 21 countries consisting of over nine thousand 13-year-old students. The study explored the students' past experiences related to science including their curiosity towards certain science topics, their attitude to science, their perception of scientists at work, and their self-identity as a future scientist (Sjøberg & Schreiner, 2005). The personal-curiosity science looks at cultural identity at the individual level however, Weinstein (1998) introduces another relevance based on cultural identity of the whole community. This concept is referred as science-as-culture.

Science-as-culture

In science-as-culture, those who understand and interpret culture determine the relevant science and what aspects of local, national, and global culture should be blended into local curriculum (Aikenhead, 2008). This concept identifies network of communities of scientific practice in students' everyday life who interact with science professionals and create unique cultural identity of scientific notion (Aikenhead, 2004). Science-as-culture embraces other relevance knowledge like the need-to-know, functional, enticed-to-know, have-cause-to-know, and personal-curiosity science categories. Aikenhead (2004) asserts that science-as-culture can be found in project-based learning that incorporate local, science-related, real-life problems in an interdisciplinary way (Barton & Yang, 2000; Roth & Désautels, 2004) and in a cross-cultural way (e.g. Aikenhead, 2002; Aikenhead, 2008). Whereas personal-curiosity science follows the knowledge centred scientific literacy, the science-as-culture belongs to socio-culture scientific literacy.

Science through Education against Education through Science

Holbrook and Rannikmae (2007) introduced the duality (science through education and education through science) based on the two preceding perspective of scientific literacy. Their discussion of the differences and similarities of this dichotomy is summarised in Table 1.

Table 1: Science through education versus Education through science compared (Holbrook & Rannikmae, 2007)

Science through education	Education through science
Learn fundamental science knowledge, concepts, theories, and laws	Learn the science knowledge and concepts important for understanding and handling socio-scientific issues within society
Undertake the processes of science through inquiry learning as part of the development of learning to be a scientist	Undertake investigatory scientific problem solving to better understand the science background related to socio-scientific issues within society
Gain an appreciation of the nature of science from a scientist's point of view	Gain an appreciation of the nature of science from a societal point of view
Undertake practical work and appreciate the work of scientists	
Develop positive attitudes towards science and scientists	Develop personal skills related to creativity, initiative, safe working, etc.
	Develop positive attitudes towards science as a major factor in the development of society and scientific endeavours
Acquire communicative skills related to oral, written and symbolic/tabular/graphical formats as part of systematic science learning	Acquire communicative skills related to oral, written and symbolic/tabular/graphical formats to better express scientific ideas in a social context
Undertake decision-making in tackling scientific issues	Undertake socio-scientific decision-making related to issues arising from the society
Apply the uses of science to society and appreciate ethical issues faced by scientists	Develop social values related to becoming a responsible citizen and undertaking science related

Model of education through science

Holbrook and Rannikmae (2007) believe that rather than science education being used as vehicle to prepare individuals with scientific knowledge to apply to solve society problems, it should prepare society with relevant science knowledge to confront its socio-cultural issues. While the former implies using education to answer the goals of science (science through education), the latter suggests using science to meet educational goals (education through science). Holbrook and Rannikmae modify Bloom’s (1956) ‘Trinitarian’ concept of domains of educational aims. Though the ‘Trinitarian’ nature is maintained, the cognitive, affective and psychomotor domains are replaced with personal, society and nature of science domains. In science teaching, the cognitive domain referred to the development of thinking skills which is related to problem-solving skills and reasoning abilities. Whereas, creativity, interest, personal development, and various forms of manipulative skills applied in relevant context are considered as belonging to the affective and psychomotor domains. However, Bloom’s educational aims have been widened recently to cover the intellectual, communicative, social, moral, cooperative, personal, and physical skills, as well as attitudes and socio-scientific decisions making (Curriculum Development Council, 1995; Biggs, 1996; Holbrook & Rannikmäe, 2002). Holbrook and Rannikmäe (2007) argue that the goals of intellectual and communicative skills, together with personal development and attitudes are all goals attributed to the development of the individual as person. These goals are focussed on development of the wellbeing of the individual student and therefore categorised as the personal domain. Holbrook and Rannikmäe (2007) considered cooperative learning which is group learning, and social, ethical, and moral values relating to interactions and decision-making within society as components of a society domain. According to Holbrook and Rannikmäe (2007) the first two domains should be general for all subjects; however the third component should be related to the attribute of a specific subject area. In science education, the third domain is considered to be the nature of science. Even though there is no particular view of the nature of science and agreements are usually reach on consensus basis, Holbrook and Rannikmäe used socio-cultural lenses to propose that the attributes of the third domain should be the acquisition and understanding of the 'nature of science in meaningful contexts, linked to enquiry teaching and problem-solving investigations' (p. 1351). Their model of nature of science education is illustrated in Figure 5.

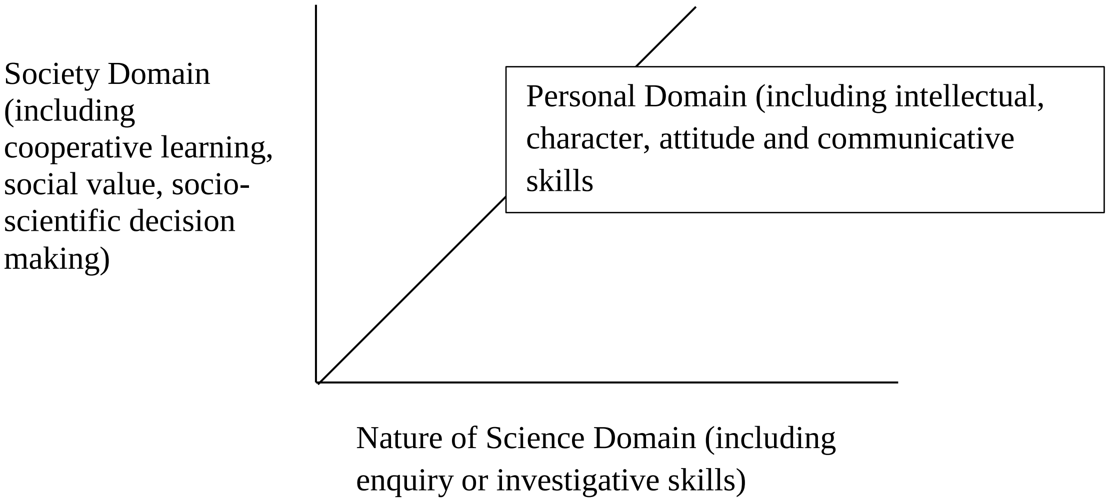


Figure 5: The three domains of education- illustrated for science education (Holbrook & Rannikmäe, 2007)

This model from the perspective of Holbrook and Rannikmäe describes "education through science" and puts the learning of the nature of science into an educational framework where personal and society developments are emphasised. The model do not invite students to critically participate in appraising wish-they-know knowledge nor to construct already defined knowledge but rather to participate in activity that leads to the achievement of educational and societal goals. The teaching approach to the model is based on activity theory (Roth & Lee, 2004; Aalsvoort, 2004). In this approach student needs, motivation, and interest, and cultural milieu form the major basis for selecting the relevance of knowledge in school science. This approach avoid over-emphasis on content (wish-they-know) to concentrate more on developing reasoning and critical skills that help to draw appropriate conclusions (Sadler, 2004; Sadler & Zeidler, 2005) from group activities. Conclusions from group activities should be shared with the entire community through development of argumentation skills (Driver, Newton & Osborne, 2000; Osborne, Erduran & Simon, 2004) and the community members should develop judicious decisions making skills to evaluate various argument by utilising scientific ideas (Kortland, 2001; Ratcliffe, 1997). It is therefore obvious that the key needed for this model of science education to promote multi-dimensional levels of scientific literacy (Bybee, 1997) for functioning within society is the development of science process skills. So far, the discussion has demonstrated that science process skills are central to the achievement of scientific literacy. The key role of science process skills is non-negotiable within both the knowledge-based and socio-cultural-based perspectives of scientific literacy. Attention is however turned to two recent major curriculum renovations, inquiry-based and practice-based science education to also assert the role of science process skills.

Inquiry-based versus Practice-based Science Education

Since 1960, science has experienced major renovations and shift towards inquiry-based curriculum. One of such curriculum documents includes the National Research Council (1996). According to the National Research Council (1996), scientific inquiry comprises multiple activities including observations, posing questions, review of literature, planning and designing investigations, reviewing experimental evidence in the field, collection of data, analysis and interpretation of data; proposing answers, explanations, and predictions; and communicating the results. Inquiry usually requires one to identify relevant assumptions in particular context and applies critical and logical thinking to offer plausible explanation. Colley (2006) states that in inquiry-based science instruction students are made to engage in one or more inquiry-based science activities. Having students engage in inquiry-based science activities in or outside the classroom could be a messy business (Colley, 2006) and as a result, various strategies for implementing inquiry-based science instruction in their classrooms have evolved. Chiappetta and Adams (2004) have identified four types of inquiry-based science instruction, each with a different focus. The first type of inquiry-based science instruction focuses on presenting and explaining ideas. Here the emphasis is on content. The aim is to confirm or verify major ideas in the curriculum. Usually, teachers provide the problem, equipment, procedure, and even the result of the experiments to the students (Staver & Bay, 1987). Thus, the students are expected to verify the known results in the experiment. The second type focuses on constructing knowledge through active learning. In the second type though students are expected to learn ideas in curriculum, it also provides opportunity for the development of the science process skills. This type is known as structured enquiry. The third type focuses on developing the ability and disposition to investigate. Here, the aim is to develop process skill with content knowledge. This type is referred to as guided inquiry where the teacher is the key person to guide almost the whole process. The teacher follows the steps of scientific inquiry by posing meaningful questions to the students (Germann, Haskins, & Auls, 1996). However, the teacher never gives the answer nor presents the steps of scientific inquiry to the students but provides clues to follow the required steps. It is expected that during the discussions, the students achieve the correct direction in the scientific process. The fourth type focuses on attaining specific science process skills. This is the open inquiry where students are free in the laboratory even in stating the problem of the experiment and conducting other scientific inquiry skills during the process. However, the Framework for K-12 Standards (National Research Council, 2012) shifts science education from teaching science as inquiry to teaching science as a practice.

Osborne (2014) provides justification for such paradigm shift. According to Osborne, the basic problem with the emphasis on teaching science through inquiry is that inquiry-based teaching misses the goal of school science. He argues that school science cannot have a goal of discovering new knowledge of the material world as espoused by the inquiry-based approach. While the goal of discovering new knowledge belong to the scientific community, in school science, the goal of learning science is ‘to build an understanding of the existing ideas that contemporary culture has built about the natural and living world that surround us’ (p. 178). The argument against inquiry-based teaching is that if the goal of school science is to help students understand a body of existing consensually agreed and well-established old knowledge, then learning of science at the school level cannot be doing science. To Osborne, scientific inquiry, that is doing science is the major methodological tool of the scientist and cannot also be the major procedure for learning science at the school level. Osborne asserts that learning science is best acquired through applying knowledge and understanding of how humans learn (Bransford, Brown & Cocking, 2000; Bransford & Donovan, 2005) and a deep understanding of the nature of the discipline. Osborne relied on Bransford and his colleague to assert the need to situate the acquisition of knowledge and understanding of science in how humans learn. In ‘How People Learn’, Bransford, Brown, and Cocking (2000) synthesized research regarding the optimal conditions that foster learning. Bransford and Donovan (2005) follow up by examining the application of the learning principles to teaching history, mathematics, and science. Their conditions for effective learning include (1) engaging prior understandings and background knowledge (2) integrating factual knowledge with conceptual frameworks through encouragement of deep understanding, and (3) supporting students in taking active control over the learning process. The first two conditions resonate with Harlen’s (1999) assertion that learning with understanding involves linking new experiences to previous ones and extending ideas and concepts to include a progressively wider range of related phenomena. Harlen argues that science process skills are needed to make linkages of ideas possible and effective. The third condition raises the need to scaffold students to take control of their own learning. Implicitly, we are called to help students to examine information critically, evaluate them and construct meaning independently. This is what we called developing the science process skills of the students. So therefore, Osborne is calling for development of higher cognitive skills rather than focusing on doing science which more often than not narrows inquiry-based learning to manipulating and handling of materials and equipment. The latter assertion surfaces in Osborne's (2014) second reason for the need for paradigm change.

A second problem with the teaching of science through inquiry, according to Osborne, has been the lack of consensus of what it means to teach science through inquiry. The notion that inquiry requires students to handle, investigate and ask questions of the material world has led to the belief that any 'hands-on' activity fulfils the basic requirement of the pedagogical approach of inquiry. Osborne assert that this form has led to (1) the notion that inquiry should always occur in the science laboratory, (2) emphasis on manipulation of materials and equipment and (3) mainly the use of inquiry to verify phenomenon. This narrow understanding of inquiry defeats and avoids the aims to develop a deeper understanding of the nature of scientific inquiry and the analysis and interpretation of data. Osborne (2014) summarises his reason for the need to change from inquiry-based to practice based in the following words:

> So the answer to the question posed about what are the problems of teaching science through inquiry is that the conception was poorly articulated and, as a consequence, poorly communicated. Moreover, the lack of a professional language that defines and communicates the categories of activity that students should experience —that is a workable classification of educational practice—undermines the professional practice of teaching science (pp. 178-179)

The Model of Practice–based Science education

According to Osborne (2015) and Osborne (2014), the model of practice-based science education illustrates the practice of scientists. He argues that the fact that the model emerged from empirical psychological studies of practice and normative philosophical studies of what scientist do make it significant scientific activity. The basis of the model is that the practice of science involves three main 'processes', which include hypothesizing, experimentation and evidence evaluation (Klahr, Fay, & Dunbar, 1993). The model has three parts. The left part involves scientists using science process skills to investigate the real world. The investigative activities include designing experiments and collecting, analysing and interpreting data. The science process skills used on the right side also involve higher cognitive skills like theorising about the world, developing hypotheses and constructing explanations (Osborne, 2015). The point of intersection illustrates scientific practice as community of practice where skills of critique and argumentation are used to refine knowledge. Here scientists are "engaged in argument about their data, contrasting their data with their theoretical predictions, and identifying flaws in both their own and others' ideas" (Osborne, 2015, p. 17).

The model of practice-based science education calls for students to engage in eight basic practices including (1) Asking questions and defining problems; (2) Developing and using models; (3) Planning and carrying out investigations; (4) Analyzing and interpreting data; (5) Using mathematical and computational thinking; (6) constructing explanations and designing solutions; (7) Engaging in argument from evidence; and (8) Obtaining, evaluating and communicating information. According to Osborne (2014), engaging students effectively in the eight practices: (a) is more effective means to helps students to develop a deeper and broader understanding of what we know, how we know and the epistemic and procedural constructs that guide the practice of science; (b) presents a more authentic picture of the scientific endeavour. The preceding discussion indicates that irrespective of the approach to science education, science process skills play a key role in the understanding of science.

The centrality of science process skills in the Ghanaian chemistry syllabus

The chemistry syllabus is organised around three profile dimensions comprising Knowledge and Understanding, Application of Knowledge, and Practical and Experimental Skills which describe learning behaviour of students. Whereas the first two dimensions (Table 2) are clearly about Bloom's taxonomy, the third dimension is about the science process skills and scientific attitude. Harlen (1999) however indicates that scientific attitudes are usually subsumed in science process skills.

Table 2: Profile dimensions and action verbs used to indicate them (MoE, 20101)

Dimension	Action verb
Knowledge and Understanding (KU)	
Knowledge	Remember, recognize, retrieve, locate, find, do bullet pointing, highlight, recall, identify, define, describe, list, name, match, state principles, facts and concepts
Understanding	Interpret, explain, infer, explain, exemplify, categorize, comment, twitter, tag, summarize, translate, rewrite, paraphrase, give examples, generalize, estimate or predict consequences based upon a trend
Application of Knowledge (AK)	
Application	Produce, solve, operate, demonstrate, discover, implement, carry out, use, execute
Analysis	Differentiate, compare, deconstruct, attribute, outline, find, structure, integrate, mash, link, validate, crack, distinguish, separate, identify
Innovation/ creativity	Synthesize, combine, compile, compose, devise, construct, plan, produce, invent, devise, make
Evaluation	Appraise, compare features of different things and make comments or judgement, contrast, critique, justify, hypothesize, experiment, test, detect, monitor, review, post, moderate, collaborate, network, refractor, support, discuss, conclude

Though the existence of hierarchy in the Bloom's taxonomy (knowledge, understanding, application, analysis, synthesis and evaluation) is largely consensus knowledge, hierarchy in the variants of science process skills (for example, observation, communication, measurement, inference, prediction etc.) usually do not attract consensus.

However, Ongowo and Indoshi's (2013) assertion that the skill of observation is the most basic skill, gives credence to the perception that scientific ideas begin with the skill of observation. Though being aware of dissent to this view (see Osborne, 2015), it is possible to develop the science process skills particularly the basic skills in order of increasing complexity starting with observation. For example, one may use one of the five senses to observe for instance the appearance of iodine. The observer therefore creates mental image(s) of what is observed. This mental image(s) may be processed and shared in the form of the science process skill of communication. What is communicated can take the form of drawing the mental image(s) created, vivid description of the image(s) using written texts or verbal descriptions. Communicating the idea that iodine is black solid may emanate from direct observation, or indirect previous experiences of the object including classroom description of the object. In the latter case, though the students may not directly observed the object using the sense of sight, hearing the description may help to create mental image similar to that collected through the sense of sight and stores for retrieval when needed. This means science process skills are not only used and developed in practical laboratory situations (Ampiah, 2004) but also can be used and developed in theoretical classroom situations. Therefore when verbs like *define, state, list* are used, these verbs act as stimuli that prompt students to communicate concepts observed or taught to them. This implies that the Knowledge aspect of the Knowledge and Understanding dimension where knowledge is recalled is subsumed in the skill of

Table 3: Structure of the Chemistry Syllabus (MoE, 2010)

communication. This analysis makes communication depend on observation either directly or indirectly. However, understanding is gained when concepts are, for instance, compared to units or other concepts. When the observed iodine is communicated as black solid with each millilitre weighing 4.9g, the communication is made more detailed and takes the form of measurement. The measurement of different objects may lead to classifications or drawing conclusions in the form of inferences or predictions. The understanding of the process of photosynthesis, for example, may lead to prediction of the health benefit of keeping plants around people with some sort of breathing difficulty during the day. This idea can be tried and evaluated using higher integrated science process skills like hypothesis, controlling variables, interpretations and experimentations. This simple example sails through all the four levels of the dimension of Application of Knowledge. This shows that all the levels of the profile dimension, Knowledge and Understanding and Application of Knowledge can be covered and explained by the science process skills. Implicitly, two assertions are admissible from the preceding discussions. These are (1) science process skills plays central role in the chemistry syllabus and (2) both the specific objectives of the chemistry syllabus and the assessment items used by WAEC (in both theory and practical papers) have underlying science process skills intended to be developed in students or to assess what science process skilled students have acquired. The classification of specific objectives in the chemistry syllabus for instance reveals that the objectives seek to develop ten different science process skills directly. These interpreting, manipulating, investigating and experimenting (Appendices A – C.

SHS 1	SHS 2	SHS 3
SECTION 1 INTRODUCTION TO CHEMISTRY Unit 1 : Chemistry as a discipline Unit 2 : Measurement of Physical Quantities Unit 3 : Basic Safety Laboratory Practices SECTION 2 ATOMIC STRUCTURE Unit 1 : Particulate Nature of Matter Unit 2 : Structure of the Atom Unit 3 : Periodicity SECTION 3 CHEMICAL BONDS Unit 1 : Interatomic Bonding Unit 2 : Intermolecular Bonding Unit 3 : Hybridization and Shapes of Molecules SECTION 4 CONSERVATION OF MATTER AND STOICHIOMETRY Unit 1 : Carbon-12 Scale Unit 2 : Solutions Unit 3 : Stoichiometry and Chemical Equations Unit 4 : Nuclear Chemistry SECTION 5 STATES OF MATTER Unit 1 : Solids and Liquids Unit 2 : Gases and their properties	SECTION 1 ENERGY AND ENERGY CHANGES Unit 1 : Energy changes in Physical and Chemical Processes Unit 2 : Energy Cycles and Bond Enthalpies SECTION 2 INORGANIC CHEMISTRY Unit 1 : Periodic Chemistry Unit 2 : Transition Chemistry SECTION 3 CHEMICAL KINETICS AND EQUILIBRIUM Unit 1 : Rate of Reactions Unit 2 : Chemical Equilibrium SECTION 4 ACID AND BASES Unit 1 : The Concept of Acids and Bases Unit 2 : Properties of Acid, Bases and acid-base Indicators Unit 3 : Classification of acids and bases Unit 4 : Concept of pH and pOH Unit 5 : Buffer solutions Unit 6 : Solubility of Substances Unit 7 : Salt and Chemicals from Salt. SECTION 5 REDOX REACTIONS AND ELECTROCHEMISTRY Unit 1 : Oxidation – reduction processes and oxidizing – reducing agents Unit 2 : Balancing redox reaction equations Unit 3 : Redox Titrations Unit 4 : Electrochemical Cells Unit 5 : Electrolytic Cells Unit 6 : Corrosion of Metals SECTION 6 CHEMISTRY OF CARBON COMPOUNDS Unit 1 : Bonding in Carbon Unit 2 : Classification of Organic Compounds. Unit 3 : Identification of elements in Organic Compounds Unit 4 : Separation and purification of Organic Compounds Unit 5 : Alkanes Unit 6 : Alkenes Unit 7 : Alkynes Unit 8 : Benzene Unit 9 : Alkanols Unit 10: Alkanoic Acids Unit 11 : Alkanoic Acids derivatives: Alkylalkanoate (esters)	SECTION 1 CHEMISTRY, INDUSTRY AND ENVIRONMENT Unit 1 : Chemical Industry Unit 2 : Extraction of Metals Unit 3 : Extraction of Crude Oil and Petroleum Processing Unit 4 :Environmental Pollution Unit 5 : Biotechnology Unit 6 : Cement and its uses SECTION 2 BASIC BIOCHEMISTRY Unit 1 : Fats and oils Unit 2 : Proteins Unit 3 : Carbohydrates Unit 4 : Synthetic polymers

The Chemistry syllabus for SHS level is for a three year programme covering SHS 1, SHS 2 and SHS 3. The topic to be taught consists of Sections which are broken down into Units which are taught to students with Specific objectives. The details of the structure of the syllabus for SHS 1, SHS 2 and SHS 3 are contained in Table 3.

For example, the Section 1 of the SHS syllabus talks about 'Introduction to Chemistry'. The Section 1 has three Units comprising (1) Chemistry as a discipline; (2) Measurement of Physical Quantities and (3) Basic Safety Laboratory Practices. Table 3 shows that SHS 1, SHS 2 and SHS 3 had five, six and two Sections respectively. The five Sections in SHS1 break further to fifteen Units while Sections in SHS 2 and SHS 3 break further to thirty and ten Units respectively. The SHS 1, SHS 2 and SHS 3 levels had 81, 112 and 50 specific objectives respectively. The Classifications of the Specific objectives in the three levels are contained in Appendices A; B and C respectively.

The WAEC theory paper 2 assesses the content covered in the Table 3. The analysis of the assessment items used by WAEC from 2012 to 2016 revealed eight different science process skills. These are communicating, calculating, inferring, predicting, drawing, classifying, interpreting and experimenting (Appendices D – H). The practical paper however, covers three main areas. These are (a) General Skills and Principles; (b) Quantitative Analysis and (c) Qualitative Analysis. The General Skills and Principles expect students to be familiar with: (i) Measurement of mass and volume; (ii) Preparation and dilution of standard solutions; (iii) Filtration, re-crystallisation and melting point determination; (iv) Measurement of heats of neutralisation and solution; (v) Determination of pH value of various solutions by colorimetry; and (vi) Determination of rates of reaction from concentration versus time curves. The Quantitative Analysis aspect includes acid-base titrations where standard solutions of acids and alkalis and the indicators, methyl orange and phenolphthalein are used to determine the following: (1) The concentrations of acid and alkaline solutions; (2) The molar masses of acids and bases and water of crystallization; (3) The solubility of acids and bases; (iv) and The percentage purity of acids and bases. The Qualitative Analysis involves: (i) Characteristic and confirmatory tests of cations including NH_4^+; Ca^{2+}; Pb^{2+}; Cu^{2+}, Fe^{2+}; Fe^{3+}; $A1^{3+}$; and Zn^{2+}. (ii) Characteristic reaction of dilute HC1 on solids or aqueous solutions and conc. H_2SO_4 on solid samples of the following: $C1^-$; SO_3^{2-}; CO_3^{2-}; NO_3^-; SO_4^{2-}; in addition to their Confirmatory tests. (iii) Comparative study of the halogens; displacement reactions. (iv) Characteristic test for the following gases: H_2; NH_3; CO_2; HC1 and SO_2. (v) Characteristic test tube reactions of the functional groups in the following simple organic compounds: Alkenes; alkanols; alkanoic acids, sugars (using Fehling's and Benedict's solutions only); starch (iodine test only) and proteins (using the Ninhydrin test, Xanthoproteic test, Biuret test and Millon's test only).

The WASSCE Chemistry Paper 3 (practical paper) consists of three alternatives, A, B and C. Each alternative paper involves at least two investigations. The quantitative aspect which is the Question 1 investigates (investigating skill) the quantitative content of an unknown sample using titrimetric method. The trimetric procedure includes handling and manipulation of materials and equipment and specific observation of end point. The entire procedure is seen as one and labelled as manipulative skill. It was noted however that if one fails to observe the right end point, the entire procedure will be wrong leading to wrong analysis but when one candidate measure 20 cm^3 and another use $25cm^3$, the different measurement will not affect the analysis. The implication is that whereas, the observation of end point is integral part of the titrimetric process, the measurement involve is separate skill which is labelled separately as measuring. In Question 1 each candidate is given opportunity to repeat the process and communicate result in the form of table. Candidates are expected to have three titrimetric processes. Each Question 1 had 3 manipulating; 3 measuring; 1 communicating and 6 Recording skills. All tasks involving calculations require candidate to remember specific algorithmic steps and actual skill of calculation (calculating skills). Tasks involve the verbs state and explain usually attracted communicating and Interpreting skills respectively.

The Question 2 which deals with the qualitative analysis comprised either one, two or three investigations. Each investigation involved series of instructions or processes (manipulation) which leads to specific observation(s) and inference(s). For example:

(a) Put all of S into a beaker or a boiling tube and add about $10cm^3$ of distilled water. Stir the mixture thoroughly and filter. Keep both the residue and the filtrate.

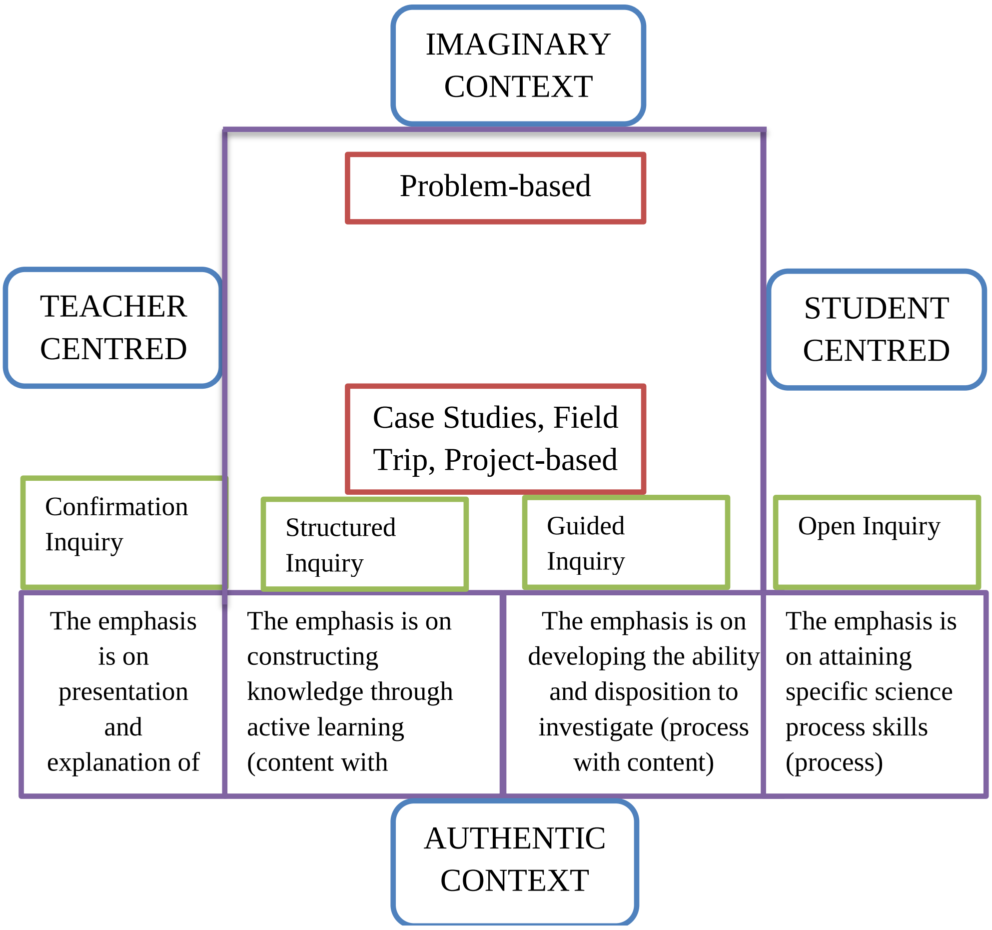
(b) (i) To about $2cm^3$ of the filtrate, add dilute HNO_3 followed by $AgNO_{3\,(aq)}$.
(ii)Add excess NH_3 solution to the resulting mixture in b (i).

(c) (i) Put residue into a test tube and add dilute HCl in drops till all of it dissolves.
(ii)To a portion of the solution from c (i) add dilute NaOH in drops and then in excess.

> (iii) To another portion of the solution from c (i) add dilute NH_3 solution in drops and then excess. (WASSCE, 2015 Paper 3, ALT C, Question 2)

The above question involves six procedures requiring specific observation(s) and inference(s). The purpose of the procedures is to investigate the qualitative content of the sample S. The question therefore examines 1 investigating skill adding up to 6 manipulating; 6 observing and 6 inferring skills. There are therefore 18 recordings (recording skills) which is communicated (communicating skill) in table form. The inference in c(i) however, led to confirmation test. The manipulating skill used to confirm the inference (hypothesis) was seen as experiment hence experimenting skill. The Question 3 examines the knowledge of general skills and principles of practical chemistry. Tasks in Question 3 attracted communicating; interpreting; observing; inferring skills.

In the Ghanaian syllabus, chemistry is expected to be taught through inquiry, case studies, projects and field trips (MoE, 2010) in order to develop what the curriculum called ‘Practical and Experimental Skills (PES). Inquiry is what scientists do in authentic real world context to discover new knowledge about the material world. The National Academy of Science (1995), however, called science education to mimic this authentic activity through its publication of the National Science Education Standards. In other words students are called to do what scientists do through inquiry based instruction. McBride, Bhatti, Hannan and Feinberg (2004), for example, state that during inquiry-based instructions students acquire science process skills which are applied to understand science concepts. They further state that ‘the process of inquiry becomes the means by which the currently accepted science knowledge is better understood' (p. 435). It is however, a common knowledge that in order to discover the currently accepted science knowledge, teachers have to get so involve in the process to the extent that the process becomes extremely teacher centred. In this case, students may get the content and missed out the science process skills. Paradoxically, experience shows also that, the content is equally likely to be missed when too much emphasis is placed in helping students to develop the skills in open inquiry where the process is extremely student centred. The difficulty in using instruction to achieve dual purpose of content and science process skills has evolved four different levels to inquiry-based instruction. The Figure 8 attempt to explain and relate the four inquiry levels of instructions to problem based, case studies, field trips and project based instructions.



The emphasis is on presentation and explanation of

The emphasis is on constructing knowledge through active learning (content with

The emphasis is on developing the ability and disposition to investigate (process with content)

The emphasis is on attaining specific science process skills (process)

Figure 6: Relationship among the major instructional approaches (Author's own construct, 2019)

These four levels of inquiry, according to Banchi and Bell (2008), are (1) Confirmation inquiry where students are provided with a question and procedure for confirming or reinforcing a previously learned idea or practising specific skills of data collection and recording; (2) Structured inquiry where students analyse data collected through a designated procedure and formulate answers to questions posed by the teacher; (3) Guided inquiry where students design and follow their own procedures to collect data and formulate conclusions that answer a question posed by the teacher and (4) Open inquiry where students formulate their own research question(s), design and conduct a procedure, collect data and communicate their findings and results.

The four inquiry levels sit in authentic context with confirmation and open inquiry being at the extreme ends of teacher and student's centred spectrum and the structured and guided inquiry lying between the ends of the spectrum as shown in the Figure 8. The figure shows that inquiry based instruction shares authentic space with project based (including case studies and field trips) but differs by being either teacher centred or student centred (Colley, 2006). Colley differentiate problem based instruction from project based and inquiry-based instruction by asserting that problem-based instruction is an instructional approach that uses real or imaginary world problems as the context for an in-depth investigation of core content. Colley states that all problem-based instructional approaches share three qualities including ill-defined problem, stated goal, and specific steps, or procedures to bridge the goal to the problem (Greenwald, 2000) with the assumption that teachers are able to provide learning environments that are full of challenging problems for students to solve. When problem based instruction is situated in real life context, it may take the form of case studies or project. For example, problem based instruction used massively in medicine, business, law and police science (Camp, 1996) usually takes the form of case studies where narrations of real life situations are given for exploration, experimentation and possible formulation of solutions. Another 'way to situate secondary school learning in real life context is to link problem solving to projects needed in the community' (Hill & Smith, 2005, p. 139). Thus problem based instruction may sit in authentic real life space as either case studies or project work. However, problem based instruction can be situated in an imaginary context as shown in the Figure 8. Posing problems in an abstract or imaginary context where students use learnt algorithmic procedure to solve is a common practice in chemistry education. A field study which is taken outside the classroom could also provide authentic real life situations which can be understudy in the form of case studies or projects. Hill and Smith (2005) believe when instruction is based on problem(s) posed in an authentic real context, students are exposed to acquire higher thinking skills, and develop creativity and reflective learning. This evidence gives credence to MoE's (2010) recommendation for the use of case studies, projects and field studies to promote science process skills at the SHS level.

Usually, no single inquiry, project or case study provides enough evidence to understand real authentic context, rather evidence from practical activities are evaluated and interpreted in view of other available evidence. Any discovered idea is linked to the big idea (Osborne, 2015; Harlen, 1999) through evaluations, both oral and written argumentation and also mathematical representations. This shows that though doing science through inquiry, projects works, case studies etc are crucial; the practices of reading, talking, writing and the use of symbolic representations are also essential tools to develop science process skills and understandings in science. Osborne (2015) considers the later practices as 'providing students with opportunities to engage in a set of literate activities that help to build an understanding of the ideas that are used to explain the phenomenon itself' (p.18). In fact, in any practical activity, learners observe correctly not only based on what their senses communicate to them but also based on their previous experiences acquired through reading and discussions with others. Usually, before a team of learners make good conclusion of their data or observations, there is almost always interaction of the data with experience at the individual level before the use of logical reasoning and argumentative skills prevail among the team members through the use of language. Thus concurring with Osborne that literacy is constitutive part of the process of understanding and explaining phenomena. Further support to literacy aspect of the development of science process skills and understanding in science is offered by Chi (2009) who gave evidence that students who discussed practical activities understood better than those who gave written report who in turn understood better than those who were simply active. It means that the concept of active learning is to engage both the physical and the mental.

It is, however, crucial to realise that curricular provisions are implemented by schools and the teachers who take students through relevant scientific activities. For example, teachers must understand and convince the school system about the rationale for exposing students to certain learning experiences. How the school system and teachers relate to the nature of scientific activity, what it means to learn science and how learning is brought about is also crucial (Harlen & Elstgeest, 1992). According to Harlen and Elstgeest (1992), the views of the school system and teachers concerning learning activities and learning of science have a profound influence on the activities teachers provide for teaching and learning and also how organisation and management of classrooms is done. In fact the role teachers adopt, the way they use equipment and materials, and the criteria they use in assessing and evaluating the success of the work hinges not only on the teachers view but also on that of the school system. The school system epitomises the belief, practice and the ethos of the school hence the promotion or otherwise of the development of science process skills depends on them as well as the teachers who are part of the system. Harlen and Elstgeest (1992) gave an implied argument that schools and teachers whose view of learning is a matter of rote memorization probably in order to pass highly consequential examination (Braun & Kanjee, 2006) will provide experiences that expose students to accurate facts and encourage them to memorize procedures and algorithms. Usually, the approach to teaching is the provision of 'information in digestible packets, each to be mastered before the next is attempted' (Harlen & Elstgeest, 1992, p. 20). In these situations, students may graduate with high grades but may forget the concepts that they used to pass the examinations. However, the most disservice offered to these students is that they may be deprived of science process skills which are essential for lifelong learning. On other hand, schools and teachers with view to develop science process skills and understanding approach teaching and learning differently with features described by Harlen (1999) as:

> …actively to seek evidence through their own senses, to test their ideas and to take account of others' ideas through discussion and using sources of information; the organization will facilitate interaction of pupils with materials and pupils with pupils; the teacher's role will be to help children to express and test their ideas, to reflect upon evidence and to question the way they carry out their investigations; the materials have a central role in providing evidence as well as arousing curiosity in the world around. The assessment criteria must include reference to process skill development and understanding of ideas, and not neglect the development of scientific attitudes (p. 21).

Though the experiences provide by the schools and teachers are essential to develop science process skills in students, it is also a common knowledge that exposing different students to the same experiences do not usually leads to the same outcome. The characteristics of the students to engage in all the practices prescribed by the curriculum and implemented by schools and teachers cannot be overlooked.

Conceptual Framework

The preceding review of literature has provided theoretical basic for the problem of the study and offers solutions and directions to the study. The literature on scientific literacy as a goal for science education provides justification for the quest to understand how science process skills are developed at the SHS level. Scientific literacy advocates for the need to gain knowledge and understanding about the world around us and also to identify societal problems and construct solutions. Review of the ideas of Harlen (1999) indicated that developing understanding of the world (developing concept of world) happens via the route of developing science process skills. This means development of science process skill has implications on achievement of scientific literacy at the SHS level and beyond.

However, to understand how science process skills are developed, there is the need for operational definition(s) of science process skills. Anderson model with 16 variants of science process skills offers such tool to understand and execute the problem of the study. The identified 16 variants not only demonstrate hierarchy, but also consist of two groups comprising basic science process skills which can be transferred to understand scientific concepts and integrated science process skills that help to offer explanations and solutions to scientific and societal issues (Akinbobola & Afolabi, 2010; Ongowo & Indoshi, 2013). The review of the Ghanaian chemistry syllabus indicated the presence of both basic and integrated science process skills as part of skills expected to be developed at the SHS level. The syllabus and the reviewed literature also prescribed activities such as reading, talking, writing, doing practical works and solving authentic problems via projects and case studies as means to developed science process skills. However, Harlen and Elstgeest (1992) indicated that the perceptions of teachers and the school system may or may not help to develop science process skills depending on the teaching and learning activities students are exposed to and how students are assessed. These theoretical perspectives thus help to identify variants like basic and integrated science process skills, perception of teachers, students and the school system on importance of science process skills and curricula experiences such as assessment, teaching and learning activities and curricula objectives that drive teaching and learning. The perspective of the researcher based on the theories outlined is that curricular and teacher focus must be concentrated on exposing learners to activities that develop both basic and integrated science process skills in order to go beyond conceptual understanding to solve scientific problem. This view is constructed in the framework contain in Figure 7. This conceptual framework gives direction to the study.

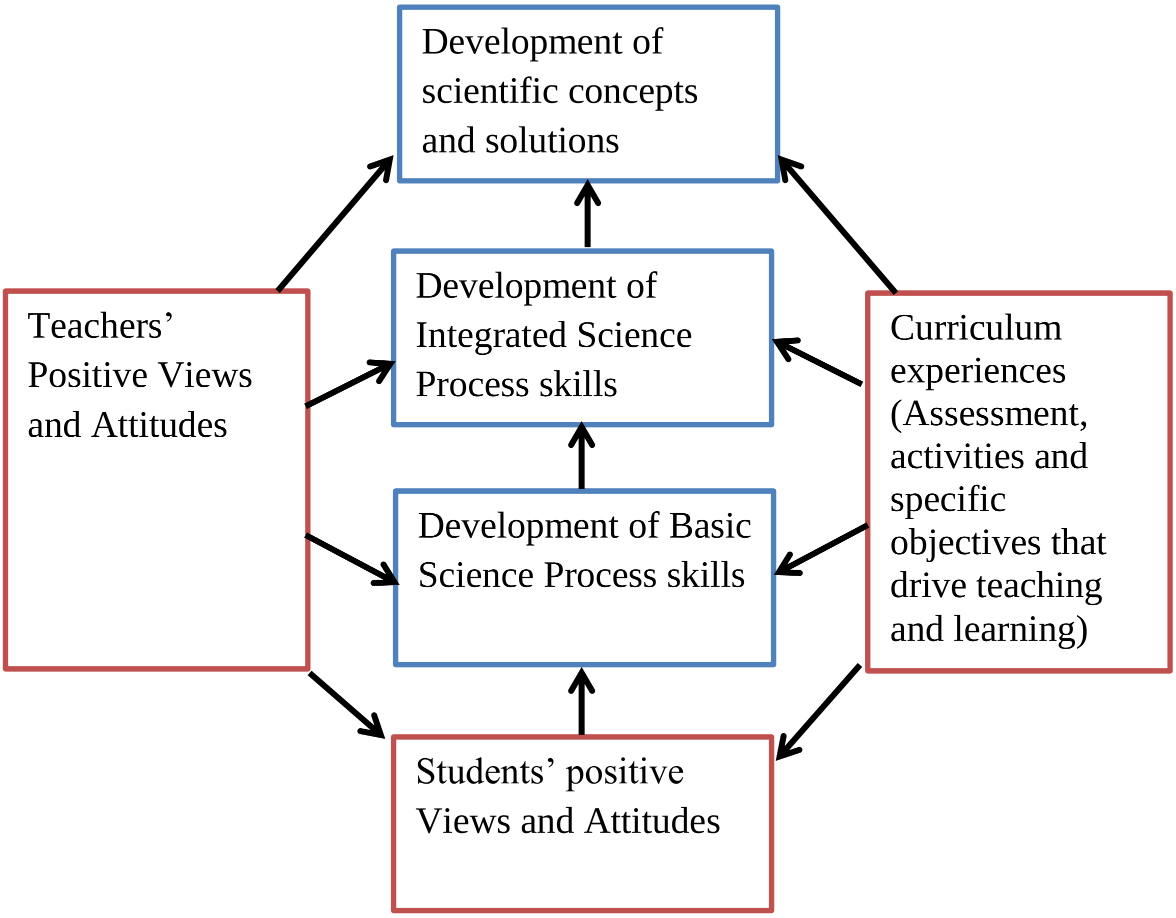


Figure 7: Framework of achieving scientific literacy through science process skills (Author's Construct, 2019)

CHAPTER THREE

RESAERCH METHODS

Introduction

This chapter covers the methodology used for conducting the study. The chapter contains the research design, population, sample and sampling procedure, research instruments, data collection procedures, data analysis, and the chapter summary.

Research Design

The research design adopted for the study was descriptive survey design with mixed-methods approach. Mixed-methods research involves the use of both quantitative and qualitative methods in a single study (Fraenkel & Wallen, 2009). However, combinations of data collection and analysis from both quantitative and qualitative traditions could be the essential feature that classifies a study as mixed-methods approach (Fraenkel & wallen, 2009). The study involved two parts, comprising document analysis and cross sectional data analysis. The survey is made up of questionnaire on teachers' and students' view on science process skills and parametric achievement test on students' development of science process skills.

Document analysis

The first part consisted of documentary data analysis (Ahmed, 2010) which involved two documents comprising WAEC past questions (2012 – 2016) and the chemistry syllabus for senior high schools in Ghana (MoE, 2010). Ahmed (2010) defines document as any written material other than a record that was not prepared specifically in response to some requests from the investigator. The two documents were specifically sourced as primary document sources to help understand how science process skills are assessed and developed as direct response to the research question one and partly provided answers to the research question two. The use of the WAEC past questions (2012 – 2016) for example, indicated careful selection, objective evaluation, synthesis and drawing of conclusion from past events in order to have present understanding of how science process skills are assessed and developed. The content analysis of these documents depicted careful use of historical events to understand phenomenon which has been described as historical research design (Cohen, Manion & Morrison, 2008).

The selection of the two documents was guided by the first two research questions. The research question one sought to find out the inherent science process skills in the WAEC examinations in the past five years and where has been the emphasis while the question two sought to find out the opportunities given to students to help them develop science process skills in school. The WAEC document was a stand-alone document to answer research question one but the chemistry syllabus complemented the cross sectional survey approach to answer the research question two. The procedure in figure 9 which was informed by White and Marsh's (2006) treatment of qualitative and quantitative content analysis was used for the document analysis. According to White and Marsh (2006), hypothesis which is predictive in nature flows from what is already known about the problem in quantitative content analysis.

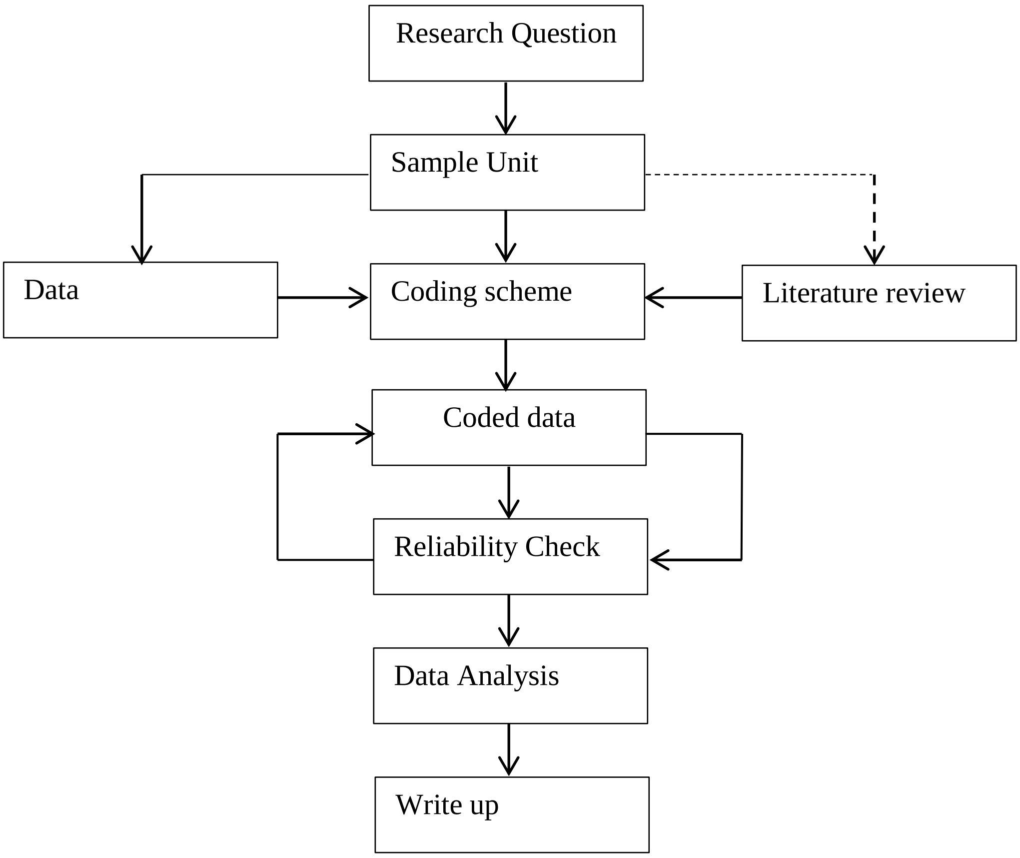


Figure 9: Flow chart of the procedure used for the document Analysis (Author's own construct, 2019)

The two research questions 'What science process skills have been assessed in the WAEC examinations in the past five years and where have been the emphasis?' and 'What opportunities are given to students to help them develop science process skills in school?' are both open questions and indicated the tendency to explore rather than to test hypothesis. The research questions however informed the sampling units. The WAEC Chemistry Papers 2 & 3 was identified as the sampling units to answer the research question one. The data were drawn from 2012 to 2016 papers with the specific question in each year paper being the unit of analysis. Figure 10 shows the relationship among the sampling unit, data collection unit and unit of analysis used in the two the documents. The unit of analysis for the syllabus was specific objectives for the various levels in the SHS. The specific objectives of the three levels (SHS 1, SHS 2 and SHS 3) and the specific questions in the yearly papers were analysed and coded with the lenses of coding scheme developed from the chemistry syllabus and other literature.

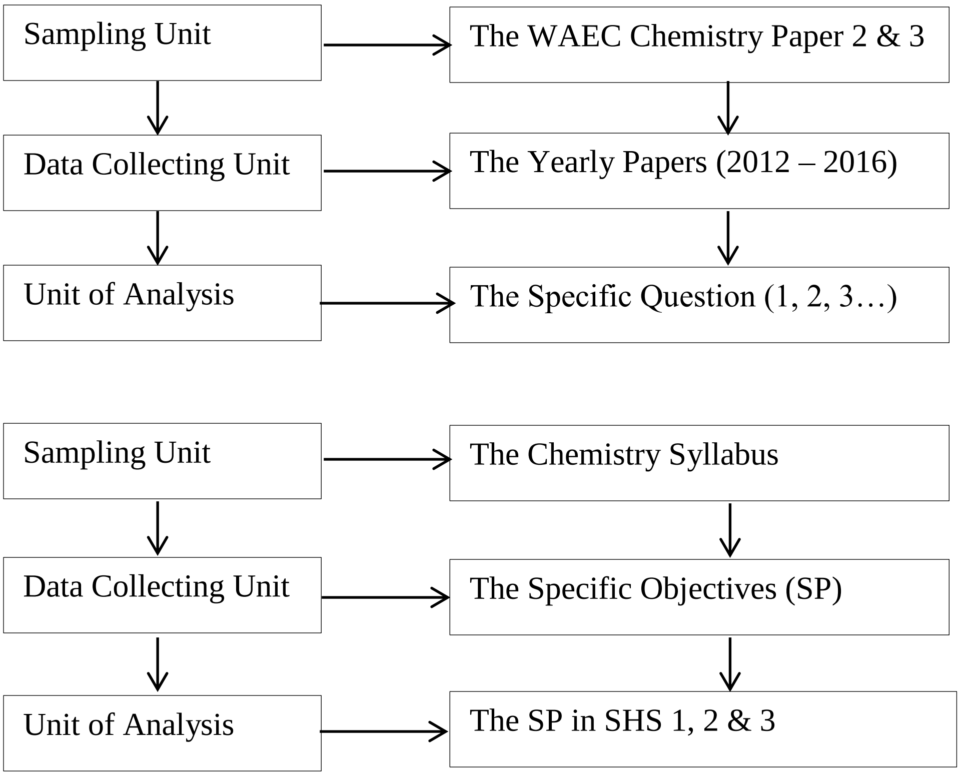


Figure 10: Relationship among the sampling unit, data collection unit and unit of analysis of the sampled documents (Author's construct, 2019)

Data in quantitative content analysis is passive and do not inform coding (White & Marsh, 2006). However the procedure for the study shown by figure 9 shows that both the research data and the known theories from literature influenced the coding scheme. The content of the documents helped to re-defined and refined views and understanding derived from the literature review. For example, science process skills sought for were restricted to skills either identified directly or inferred from the Ghanaian Chemistry syllabus and also definitions given to some of the skills were influenced by the nature of the questions in the WAEC past questions. This feature of the data collecting units influencing how data is coded and defined belongs to the realm of the qualitative content analysis. The final scheme was used to code the data and the coded data subjected to careful reliability checked which in some occasions resulted in recoding and rechecking. The coded form of the specific objectives (Appendices A – C) and that of the specific questions in the WAEC document (Appendices D – H) were analysed further and reported. The coding scheme which included identified science process skills and their definitions is contained in Appendix I.

Cross sectional survey

The cross sectional survey design was adopted to ensure economical and efficient data collection approach which allows gathering of large data from representative sample on a one-shot basis (Cohen *et al*, 2008). This approach is essential since the object of the study is to understand how science process skills are developed. Relying on information gathered from the representative sample of the population enables generalizations to be made. Also in order to have a general view of the issue under investigation and test the hypothesis raised in the study, there is the need to generate numerical data that offers the opportunity to describe, infer and explain the phenomenon. These issues are best addressed using survey design. Cohen, Manion and Morrison (2008) raised four main considerations to be made in planning survey. These considerations include decisions on the appropriate solutions required having a clear understanding of the problem objectives of the study. The first research question is fully taken care of by the documentary analysis. The outstanding problems were solution for part of the research question two, and answer for the research questions, three, four and five; and that of the hypotheses. The flow chart in figure 11 shows procedure involved in the cross sectional survey approach.

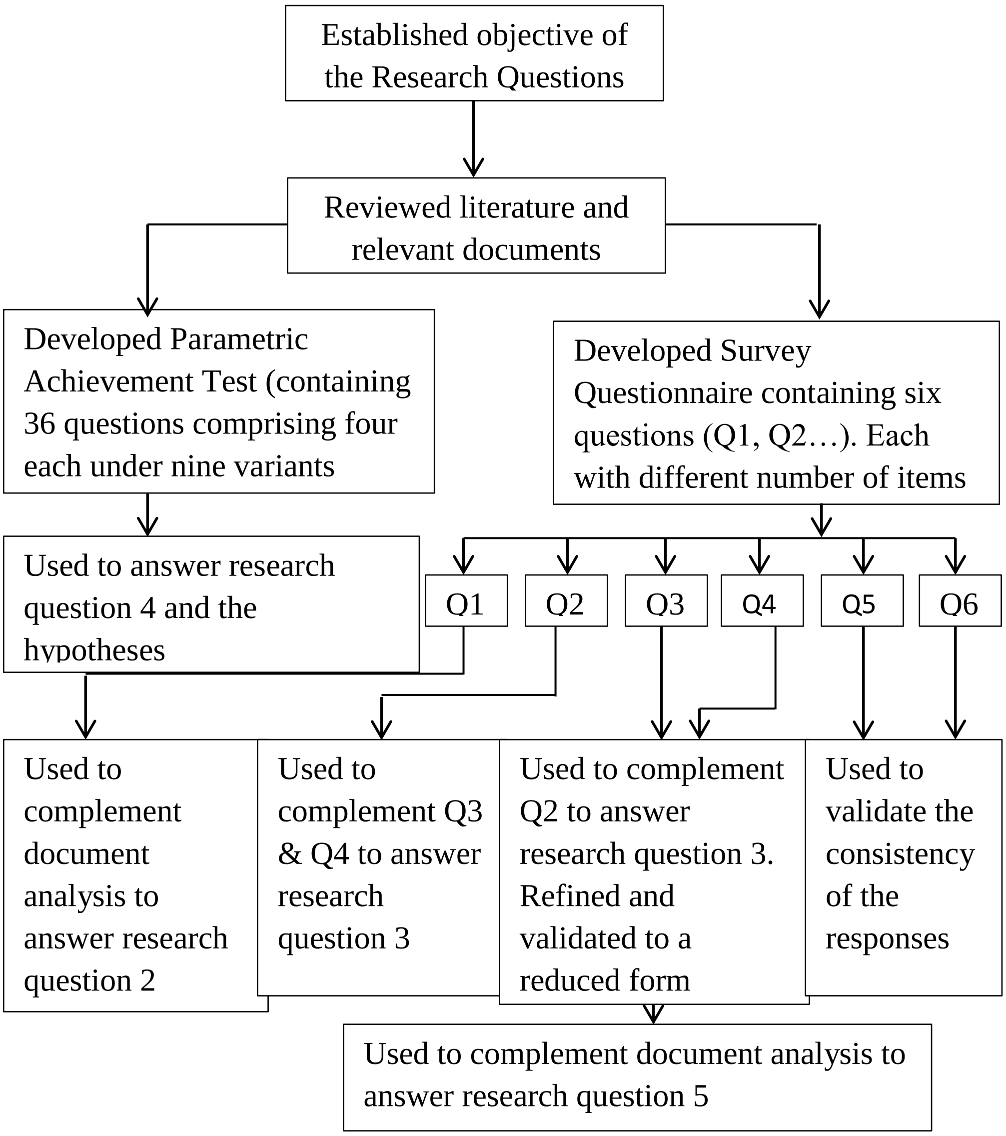


Figure 11: Flow chart of procedure involved in the survey design (Author's Construct, 2019)

Careful review of literature and relevant documents helped to formulate solutions in the form of questionnaire and parametric achievement test. The questionnaire contains six main questions with each question containing varying number of items. The question one (Q1) is designed to solicit response to complement the document analysis to answer the research question one.

The responses from questions 2, 3 and 4 (Q2, Q3 and Q4) complemented each other to answer the research question three. The refined and validated form of the Q3 and Q4 complemented the documentary analysis to provide solution for the research question five. The responses from Q5 and Q6 are designed to test the consistency of the responses. The analysis of the responses from Q5 and Q6 indicated how meticulous and serious the respondents were in attending to the questionnaire. The parametric achievement test contains 36 test items comprising four items each for nine science process skills variants designed to answer the research question four and the hypotheses.

Strength and weakness of the design

The document analysis offered the collection of evidence in its natural state with the researcher's role as non-participant or indirect observer who exerts little or no effect on the data. It also allowed longitudinal view of how science process skills are assessed and developed over five-year period. This advantage is not possible for cross sectional survey, observational studies or in-depth interview method given the time constraint on the study. The cross sectional survey also offered certain strength for the study. These included: (i) Cost effectiveness – large data were collected from about 80 respondents within two hours using the two research instruments. To collect such volume of data by observation method or in-depth interviews would have taken several visits to the school. These alternative methods of data collection would have increased cost in terms of transportation fare to the researchers, time and inconvenience to both the researchers and the school including students and teachers. (ii) Generalizability – the design allowed probability sampling techniques which captured representative sample for generalisation.

This strength of the design adopted is not available to qualitative method of data collection. (iii) Reliability – respondents were asked the same standard questions which were developed through rigorous literature review and validations. (iv) Versatility – the use of survey is common and easily applies in collecting data from different manner of people and professions. Two basic weaknesses were also identified. The first is the issue of inflexibility. The instruments contain standard questions which were used on all respondents. Unlike in-depth interviews where respondents who had difficulties in understanding questions posed to them could ask for clarification, the respondents covered largely did not have such opportunity. Respondents who experienced some of the questions as incomprehensible may also give response(s) which did not represent their view. Such situation borders on the second weakness which is the issue of validity.

Study Area

The sources of data for the documentary analysis are documents which guide and assess teaching and learning in Ghana. However, the survey data are collected from the students and teachers in the Central Region of Ghana. Aside, central region being the accessible population, the region has all the three categories of Senior High Schools (SHS) identified in Ghana (GES, 2016). GES (2016) put all SHS in Ghana into three Categories – A, B and C schools based on academic performance and facilities available to the schools. Since GES assumes schools under the same category to have similar characteristics, it is inferred that locality is not the defining variables for school's characteristics; rather it is the category of the school that determines the character of the school. Central region has all the three school categories, the selection of the region therefore, provides good representative to generalise findings from such study. Central region has 77 schools with 36 schools offering General Science as programme where students select chemistry as a subject. The 36 schools comprising 17 Category C schools (including 4 private schools which are not categorised), 12 category B schools and 7 Category A schools, covering 17 out of 20 education districts in the region.

Population

The population consisted of 36 schools comprising 17 Category C schools, 12 category B schools and 7 Category A schools covering 17 out of 20 education districts in the region. The sampling frame of the population involved chemistry teachers and students in all the 36 schools.

Sampling Procedure

The sample size consisted of 904 students and 85 teachers in 20 schools. The units of analysis were category of schools, students, teachers and gender of students. Multistage sampling is used as shown in Figure 12. 20 schools were randomly selected. The sampling units were therefore stratified into the three school categories. The result comprised five category A schools, eight category B schools and seven category C schools. The category A schools consisted of a girls' school, three boys' schools and a mixed school. Combination of random and census sampling were used to balance gender taking into consideration the number of students available in each school. Table 3 shows how 183 males and 169 females were sampled in category A schools.

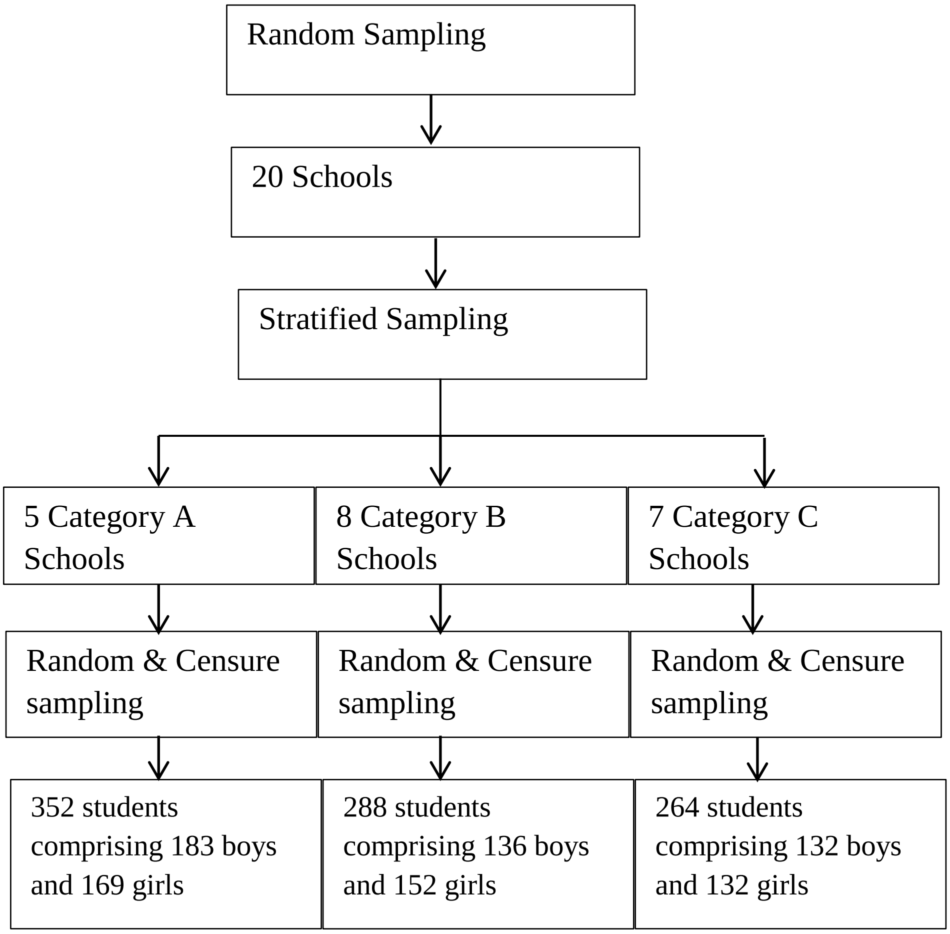


Figure 12: Multistage sampling strategy (Author's construct, 2019)

Table 4: Sample and Sampling technique in category A schools (N = 352)

School	Male	Female	Sampling Strategy
1	0	147	Randomisation
2	50	0	Randomisation
3	50	0	Randomisation
4	50	0	Randomisation
5	33	22	Census
N	**183**	**169**	

Author's Construct, 2019

In the first four schools random samples were used as shown in Table 3 but in the case of the last school, an intact class was census. All schools sampled in category B and C schools were mixed schools. In the category B schools, 40 students were randomly selected from seven schools. However, due to school activities only 8 students were available in the last school. The total number of students sampled in category B schools was 288 comprising 136 boys and 152 girls. The number of students sampled in category C schools was 264 comprising 132 boys and 132 girls. The sampling strategy used was combination of randomisation and census. All chemistry teachers available and were willing to participate were given the questionnaire to fill. The number of teachers who participated in the study were 85 consisting of 45 females and 40 males.

Data Collection Instruments

Two survey instruments are used. One was questionnaire on teachers' and students' view on science process skills (Appendix J) and the other is a parametric achievement test on students' development of science process skills (Appendix K).

Questionnaire on teachers' and students' view on science process skills (QTSVSPS)

The questionnaire on teachers' and students' view on science process skills (QTSVSPS) (Appendix J) contains six questions. The question one was constructed using eight item activities/practices (doing science, talking science, writing science, reading science, representing science, project work, case study and field trip) derived from literature review. The question invites teachers and students to rate on a five-point Likert scale according to how often they engage in those activities to help them develop science process and to solve scientific problems. Five of the items/activities are based on Pearson, Moje and Greenleaf's (2010) pedagogical practices which are necessary for the teaching of science. These practices include doing science, talking science, writing science, reading science and representing science. Osborne (2015) agrees to the need for all the five practices when he argued that doing science (practical work) has been overemphasised in science education. Osborne reasoned on the line that science is a set of ideas and teachers of science should help students to understand the ideas and the reasoning behind those ideas. To Osborne (2015), executing these two tasks - understanding the ideas and the reasoning that led to its establishment effectively requires all the five practices just as practise by scientists. The Ghanaian Chemistry syllabus also expects science process skills to be developed via project works, case studies and field studies. These three practices were added to the five to explore their extent of usage in question one. Teaching and learning about science involve three important areas- scientific knowledge, science process skills and scientific attitude. Harlen (1999, p.130) views these three as 'faces of a solid three-dimensional object … having no independence existence … yet can be described, changed and evaluated'. The question two was constructed using the three important area of science. The question two gives the opportunity to rate the three according to their importance on a five-point Likert scale. The questions, three, four, five and six contains 14 item science process skills repeated in each question. These questions were adopted from Molefe and Stears (2014) with some modifications to suit Ghanaian situation. While question three rate the items according to their perceived importance, question four rate them according to how students and teachers perceived their occurrence at the SHS level. Question five and six select four most and least important of the 14 items respectively. The 14 science process skills items selected were originally developed and validated by Coil *et al* (2010) as part of 22 items. The construction of the questionnaire went through processes that ensured construct validity, content validity and reliability. The questionnaire was tested with students sampled from the sample frame but not part of the sampling unit. The feedback helped to identified items that were ambiguous or difficult to comprehend. The worded of such items were clarified. Interaction with some of the students who answered the questionnaire indicated that the students understood what they were requested to do and that the questionnaire is able to solicit students' view on the development of science skills. The analysis of responses from questions 5 and 6 was an indication of how meticulous and serious the respondents were in attending to the questionnaire. The correlation of the responses of the four most important science process skills against the four least important science process skills was – 0.8027. The consistency in the responses shows that the students understood the questions and responded to the questions in the accordance to their knowledge of the events under investigation. All the process discussed were to ensures and give credence to the ability and trustworthiness of the instrument.

Students' development of science process skills index Test (SDSPS)

Appendix K shows SDSPS, a parametric achievement test comprising 36 questions that assess nine higher order science process skills relevant to the SHS syllabus. There are four questions for each science process skill. The science process skills under examination include Observation (questions 1-4); Measurement (questions 5-8); Classification (questions 9-12); Inference/Prediction (questions 13-16); Communication (questions 17-20); Controlling variables (questions 21-24); Data interpretation (questions 25-28); Hypothesis (questions 29-32) and experimentation (questions 33-36). These skills are all relevant to the Ghanaian SHS students (MoE, 2010) and were also contained in science process skill instrument used with science attitude questionnaires to determined relationship between the science process skills and science attitude among Palestinian Secondary School students (Zeidan & Jayosi, 2015). Though the style of construction of the test was modelled around that of Zeidan and Jayosi's, the content was based on Ghanaian context. After construction, proof reading and validation by chemistry teachers, the reliability of SDSPS instrument was checked using 42 SHS 3 students within the population frame. The difficulty or otherwise of any science process skills is found to be context dependent (Harlen, 1999). The four items under each science process skill is designed under different contexts. The items are therefore made discriminately to explore how students have developed each skill under different contexts. The 42 SHS 3 students comprised of randomly selected 21 students from form three science A and B students. These two classes are parallel classes with similar abilities. The Cronbach's Alpha reliability of the parametric achievement test obtained was 0.706. According to Pallant (2005), Cronbach's Alpha should be above 0.7. The analysis of the alpha values obtained therefore shows that the reliability of the SDSPS is acceptable.

Data Collection Procedures

The researcher, together with two assistants visited the selected schools with letters of introduction from the Head of the Department of Science Education. Though, some data were taken from some schools on the same day letters were taken to the schools, it took an average of two weeks for some schools to grant access due to protocols in the schools. Data for the two questionnaires were taken from the selected schools between 1st February, 2018 and 23rd March, 2018. Students filled both questionnaires at a sitting. The average time to complete the SDSPS instrument was 40 minutes and that of QTSVSPS was 30 minutes. Students were given SDSPS to fill and after 40 minutes those who had finished were given the QTSVSPS instrument. Though students were ensured they were not being tested, they were encouraged to answer the questionnaires independently to the best of their abilities. The questionnaires were collected at the end to ensure 100% return rate.

Data Processing and Analysis

Data processing

The response from SDSPS instruments were marked for each student and entered into Microsoft Excel programme using 1 and 0 for correct and wrong answers respectively. This approach allows detail answers for each participant across the 36 items in the instrument instead of entering just the cumulative score of each student. The response for QTSVSPS instrument were also entered into Microsoft Excel programme using 1,2,3,4 and 5 for questions 1 to 4 according to students' reaction to the five-point Likert scale. However, 1 and 0 were entered to show selected and not selected respectively for questions 5 and 6. This indicates which of the 14 items were selected or not selected for the most or the least important science process skills. The marking and entering of responses were independently validated. The data were entered according to the three categories of schools (A, B and C), gender and chemistry teachers. The categories of schools, gender and chemistry teachers represented the units of analysis of the study.

Data analysis

Research question 1

What science process skills have been assessed in the WAEC examinations in the past five years and where has been the emphasis?

The verb or verb phrase in the specific questions in WAEC Papers 2 & 3 were mapped against the definition in the coding scheme (Appendix I). The coded forms of the data (the assessment papers 2012 to 2016) are found in Appendices D to H. The frequencies of the science process skills identified were tallied and then descriptions and percentages used to answer the research question one.

Research question 2

What opportunities are given to students to help them develop science process skills in school?

This research question two is answered by (1) analysing the specific objectives of the chemistry syllabus document for science process skills based on definitions in Appendix I, (2) analysing students' and teachers' responses to item Q1 which comprises eight activities in the QSTVSPS instrument. The classification of the specific objectives for SHS 1, SHS 2 and SHS 3 are found in appendices A to C. The frequencies of the science process skills identified were tallied and descriptive statistics and graphs used to analyse them. The proportions of respondents responding to the various ranking of the item 1 of the QSTVSPS instrument are coded on five Likert scale 1, 2, 3, 4 and 5. Descriptions and percentages were then used to answer the research question.

Research question 3

What are SHS chemistry teachers' and students' perceived importance and occurrence of the development of science process skills?

Descriptions and percentages are used to analyse the coded responses of teachers' and students' rating of the importance of science process skills among scientific concepts and scientific attitudes in the Q2 of the QTSVSPS instrument. Refined and validated form of the variables in Q3 and Q4 are used to complement the solution of this research question using descriptions and percentages.

Data refining and validation

The 14 science process skills used in questions 3, 4, 5 and 6 of the QTSVSPS were refined and validated to form reduced constructs which were of significant important in science education. The Table 4 shows the interpretability of the constructs and Cronbach's Alpha reliability test showing consistency of the items under each construct.

Table 5: Reduced constructs and consistency tests of their constituents

Factor	Item (s) involved	Alpha value
Critical Thinking	Predicting: forecast future observations on the basis of present trends or previous knowledge Classification: grouping and organising objects or attributes Being able to infer plausible reasons for failed experiments	0.801
Mathematical/ Statistical Skills	Interpreting data: graphs and tables Understanding basic statistics Creating appropriate graph from data	0.741
Experimentation/ Problem Solving Skills	Problem solving/critical thinking Ability to design an experiment: identifying and controlling variables Measuring: understanding concepts of accuracy and precision Recording and communicating information: understanding forms of information or data representation (i.e., verbal, written, pictorial and mathematical forms)	0.803
Argumentation Skills	Questioning: raising questions that are testable, measurable and repeatable Observing (and comparing): proficiency in describing patterns , ordering and sequencing events Interpreting data: ability to construct an argument from data Ability to create a testable hypothesis	0.820

Author’s Construct, 2019

The reduction process was done by analysing the factors involved, collapsing them into reduced variables and testing for internal consistency of various items under each construct. According to Pallant (2005), alpha ranging between values of 0.7 to 0.8 is acceptable and that of 0.8 to 0.9 shows good internal consistency. All the four constructs are prominent factors in scientific inquiry. Argumentation skill is one of the skills that relate evidence to theory. Argumentation uses data to support claims (Watson, Swain & McRobbie, 2004). Argumentation involves careful observation of data, patterns and sequence in order to question and to raise issues. The testability, measurability, repeatability of questions raised is considered in argumentation space through engagement of data and theory before used to guide experimentation. The development and rejection of hypothesis are also influenced by argumentation skills. The preceding discussion explains why the responses aggregated observing, questioning, construction of argument and development of hypothesis with consistency of 0.820. The critical thinking skill though unique is inherent to argumentation skills as well as the other constructs. Critical thinking skills examine and draw conclusions and explanations from data using established rules and theory. Three skills aggregated well for critical skill with consistency of 0.801. These are predicting, classifying and inferring. The experimentation/problem solving skill is constituted with problem solving, designing of experiment, measurement, and recording and communicating evidence with reliability of 0.803. The mathematical/statistical skill consisted of creating graphs, interpreting graphs and tables and understanding basic statistics with consistency of 0.741. The responses of respondents to the constituents of each construct are collapsed into the appropriate construct and used to answer research question raised using descriptions and percentages.

Research question 4

What science process skills have SHS 3 students developed at the tail end of their school programme to enable them write the WAEC examination in practical chemistry?

The marked and recorded responses from the SDSPS instrument were converted into percentages. Each of the nine variants consisted of four questions. The numbers of questions scored correctly under each variant for each student participant was calculated out of four and expressed in percentages. The analysis however was done according to the category of school as unit of analysis. Descriptive and inferential statistics were used to reveal how each category of school performed. The performance of schools to the test items was operationalized as level of development of science process skills among the schools.

Research question 5

What factors influence the development of science process skills by SHS chemistry students?

This question is answered by analysis of the trend in the qualitative data, the reduced factors and correlational methods to explore the relationship among the various variables.

Null hypothesis 1(H_O1)

There is no significant difference among type of schools attended by students in developing their science process skills.

The analysis was done using Analysis of Variance (ANOVA). Since there were three categories of schools, Post Hoc test was used to determine which category of schools was different. There were also nine different science process skills used in the achievement test. Multivariate Analysis of Variance (MANOVA) and Post Hoc analysis were used to determine whether there were significant differences in any variants among the categories of schools.

Null Hypothesis 2 (H_O2)

There is no significant difference between the genders of students in developing their science process skills.

The analysis of variance (ANOVA) is used to test mean differences in gender without Post Hoc test. There is no Post Hoc test because there are only two independence variables, males and females. Multivariate analysis of variance (MANOVA) and Post Hoc analysis were used to determine whether there were significant differences in any of the science process skills' variants between males and females.

Limitations

Limitations with respect to resources, time and space imposed data limitation. For example, data collection is restricted to central region which is further circumscribed to 20 schools out of 36 schools identified to offer chemistry as an electives subject in the region. Though efforts were taken to ensure validity of the survey, respondents who still felt that they were not encouraged enough to give accurate and honest response could not have been helped like it would have been in for example, in-depth one on one interview. Those who had no opinion or unaware of the reason to select any of the option in the questionnaire did not have the opportunity to express themselves. Some respondents actually left empty spaces. Those were not coded since it was difficult to determine whether empty spaces indicated lack of opinion or evidence of respondents actually forgetting to tick any of the option. Respondents were not given opportunity to give reasons for the options they selected in the achievement test. This made it difficult to detect those who guessed answers.

Ethical considerations

This aspect borders on ethical issues and the need to protect the interest of the participants. The design of the study protected the individual schools including teachers and students who were the sources of data collecting unit by making the entire student participants, teacher participants and the categories of schools the units of analysis. This approach of the design ensured confidentiality and anonymity. The issue of confidentiality and anonymity were further ensured by the accompanied letter of introduction (Appendix L) during the data collection exercise. The items in the instruments used were not too many nor lengthy. This ensured less stress and avoided unnecessary pain to the respondents. The natures of the questions were not over-intrusive and respondents were not coerced but consented.

Chapter Summary

This chapter started with signpost of the content of the methodology. It then proceeded to discuss the design to be used for the study. The targeted population, sample frame and sampling procedures were identified and elaborated. The constructions of the research instruments were discussed indicating how construct and content validity including reliability were ensured. Data collection procedures which included when and how data were collected and problems encountered were also described. Data processing and analysis were described to include data editing, entry and how data were analysed according to the research questions and hypotheses. The chapter also raised and discussed limitations in the study and ended with summary of the chapter.

CHAPTER FOUR

RESULTS AND DISCUSSION

Introduction

In this chapter, the findings from the study are presented and discussed to answer the research questions and hypotheses.

Basic and Integrated Science Process Skills in WASSCE Chemistry Papers 2 and 3

Research question 1 sought to find out the science process skills assessed in the WAEC examinations in the past five years and where the emphasis has been.

The content of the WASSCE Paper 2 was analysed to identify fourteen science process skills in the chemistry syllabus which were assessed. These fourteen science process skills comprised nine basic science process skills and five integrated science process skills. Table 6 shows the basic science process skills contained in the WASSCE paper 2

Table 6: Basic Science Process Skills in WASSCE Chemistry Paper 2 (2012 to 2016)

	OB	ME	RE	COM	CAL	INF	PRE	DRA	CLA	Total
2012	0	0	0	41	9	4	5	0	1	60(19.2)
2013	0	0	0	44	8	0	0	1	0	53(16.9)
2014	0	0	0	40	5	2	4	2	0	53(16.9)
2015	0	0	0	34	7	13	0	2	0	56(17.9)
2016	0	0	0	38	6	5	3	1	1	54(17.3)
Total	**0**	**0**	**0**	**197(62.7)**	**35(11.1)**	**24(7.6)**	**12(3.8)**	**6(1.9)**	**2(0.6)**	**276(87.9)**

Author’s Construct, 2019

OB=Observing; ME=Measuring; RE=Recording; COM=Communicating; CAL=Calculating; INF=Inferring; PRE=Predicting; DRA=Drawing; CLA=Classifying;

The analysis shows that *communicating* skill which involves communicating learnt scientific concepts and ideas is the prominence skill assessed. It was surprising, that *communicating* skill, which communicates scientific knowledge, should rather dominate in an assessment paper supposed to emphasise in application of knowledge. According to MoE (2010, p. xi), the 'Paper 2 will consist of structured questions or essay questions, essentially testing *Applying Knowledge*, but also consisting of some questions on *Knowledge and Understanding*'. If the objective of the Paper 2 is to assess essentially application of knowledge then one may expect that *Observing*, *Measuring* and *Recording* may also be used since these skills are commonly applied in the everyday activities of students. However, it was observed that these three basic science process skills, *Observing*, *Measuring* and *Recording* which were identified in the chemistry syllabus were not assessed directly by the WASSCE Paper 2 (2012 to 2016). For example, objects and events are observed using our five senses. Students could be made to observe and describe specific quality that makes two atoms for instance, isotopes by examining a drawing or picture rather than just soliciting recall knowledge of isotopes. Identifying the quality, shows a deeper understanding and ability to use knowledge or concept in a novel situation than merely asking them to communicate concept learnt by either defining or stating them. The skill of *Communicating* occurred 197 times out of 314 occurrences of all the skills identified in the Paper 2 from 2012 to 2016. Students may communicate their learnt ideas or observations verbally, in writing, or by drawing pictures, the use of graphs, tables, charts, maps, diagrams, and visual demonstrations. This view of communication seems to suggest that the skill of *Observing* precedes the skill of *Communicating*. This in turn implies that the latter is more complex and difficult in terms of cognitive processing. However, science process skills are found to be domain dependent (Harlen, 1999). That is to say, that the complexity and difficulties in the skills depend on how and where the skills are applied. This is explained by personal experience as a teacher practitioner, that though majority of students easily define concepts like compounds, elements and mixtures, only few of them are able to identify element, compound and mixture when they are asked to select the representations of these concepts as shown in Figure 13.

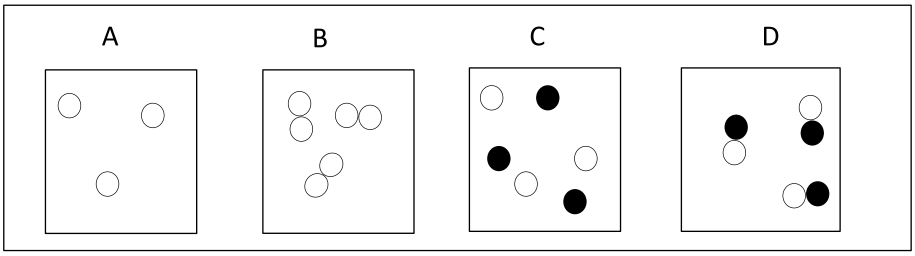


Figure 13: Boxes of elements, compounds and mixtures represented by two different atoms ● ○

These experiences make the observed style mostly used to assess the skill of *Communicating* over the period under study a bit worrying. The skill of *Communicating* was observed mainly in a form of defining, stating and describing concepts learnt. For example, in 2014, nine items were identified in question 5. Those nine items were all coded *Communicating* with the usual features of recalling knowledge or concepts.

(a) (i) Define the term isomerism.
(ii) Describe briefly the bonding within a molecule of benzene..
(iii) What would you observe when benzene is added to the following reagents:
(α) neutral $KMnO_{4(aq)}$;
(β) bromine water.
(b) (i) Define the term fats.

(ii) (α) Describe briefly the production of the traditional soap.
(β) Write a balanced equation for the reaction in (b) (ii) (α).
(γ) Name the by-product of the processes in (b) (ii) (α).
(c) State what you would observe when freshly tapped palm-wine is left to stand for a few days. (WASSCE, Paper 2, 2014, Q5)

The prominence placed on *Communicating* skill (62.7%) also casts doubt on the assertion that the Paper 2 essentially tests 'Applying Knowledge'. Rather the evidence shows that the Paper 2 places emphasis on 'Knowledge and Understanding' domain of the profile Dimension in the chemistry syllabus. The basis of this conclusion is seen in the fact revealing that 62.7% of the items in the Paper 2 (2012 to 2016) demanded students to communicate their acquired knowledge in the form of stating, listing and describing scientific concepts.

The second science process skill in order of prominence is *Calculating* science process skill. This science process skill is used usually in problem based situations. The prominence given to *Calculating* science process skill is however not surprising because the chemistry syllabus is replete with several opportunities to apply this science process skill. However, it was observed that this science process skill is usually applied in abstract and imaginary situations outside the experience of the student rather than applying in authentic everyday situations.

(ii) A mixture of gases with total pressure of 120k Nm^{-2} consists of 0.175 moles of hydrogen, 0.067 moles of nitrogen and 0.025 moles of oxygen at 25^{o}C.
Calculate the (α) total volume of the gaseous mixture;
(β) partial pressure of hydrogen in the mixture. [R = 8.314 Jk^{-1} mol^{-1}] (WASSCE, Paper 2, 2014, Q6 cii).

Most laboratories at the SHS level do not have equipment to collect gases, neither are there instruments to determine the pressure of gasses and their mole fractions. The problem posed (WASSCE, Paper 2, 2014, Q6 cii) is therefore abstract and imaginary to most students. However, students are expected to analyse the problem and recall algorithmic procedures in a form of formula to solve the problem posed. This approach to problem solving represents knowledge- centred scientific literacy where emphasis is placed on scientific content which includes development of scientific knowledge, practices, and habits of mind (Kelly & Brown, 2003; Roth & Lee, 2002). The socio-cultural-centred scientific perspective however expects problems to be situated in the socio-cultural milieu of the students to meet their everyday life challenges.

The third prominence basic science process skill is *Inferring*. *It* depends on *observing* science process skill. However, unlike observations, which are direct evidence gathered about an object, inferences go beyond appearances to offer plausible explanations or interpretations that follow from the observation. For example, a student adds an acid into a test tube containing a colourless solution whose content is unknown. The addition of the acid generates colourless bubbles which extinguishes a flame from a burner. Plausible inferences based on the observation can only be made if one is privy to some other theoretical information beyond the observations. The observer should for example know that the bubbles indicate the presence of gas being released from the solution and the gas that extinguishes flame is carbon dioxide. Coupled with the knowledge that carbonates releases carbon dioxide on addition of acids, inferable explanation then, could be made that the ensuing observations occurred because the unknown sample contains carbonate. Accurate and precise observations of things in our environment lead to inferences, and interpretation and explanation of events around us. The skill of *Inferring* occurred 24 times representing 7.6%. Like the science process skill of *Calculating*, but unlike *Communicating* which is mainly identified in the 'Knowledge and Understanding' domain, *Inferring* science process skill belongs to the 'Application of knowledge' domain of the profile dimension.

> …If G reacts with ethanol in the presence of concentrated H_2SO_4 to form a sweet liquid H, deduce the structures of G and H (WASSCE, Paper 2, 2012, Q3 cii).

For example, the question (WASSCE, Paper 2, 2012, Q3 cii) requires students to compare the pattern of observations to their previous knowledge. The precise and accurate nature of the narration of observations and the students' theory concerning what is being described leads to correct conclusion of what the nature of the compounds G and H should be. *Inferring* science process skill appeared in all the years except 2013. This is seen in Figure14.

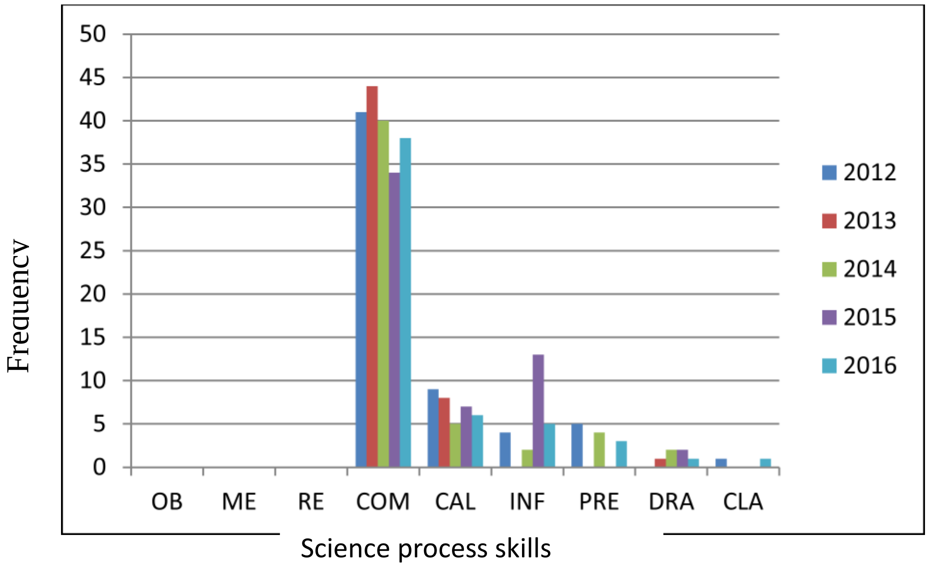


Figure 14: Basic Science Process Skills in WASSCE Chemistry Paper 2 from 2012 to 2016 (Author's Construct, 2019)

Figure 14 shows pictorially that unlike the top two science process skills in terms of prominence (*Communicating* and *Calculating*) which were assessed every year from 2012 to 2016, the other science process skills (*Inferring*, *Predicting*, *Drawing* and *Classifying*) were assessed in some of the year papers over the period under study. The fourth science process skill in order of prominence is *predicting* which appeared in all the years except 2013 and 2015. This science process skill occurred 12 times representing 3.8% of all the science process skills assessed from 2012 to 2016. The science process skill of *Predicting* concerns the ability to make evidence based guesses about the outcomes of future events based on present observations. Scientific prediction is also like using present observations to foretell future observations. Prediction is based on both good observations and inferences made about observed events. Supposing, the preceding colourless solution inferred to contain carbonate was prepared from a sample taken from a particular soil then based on further observations and inferences the alkalinity of the soil or even the ability of the soil to sustain a particular plant may be predicted. Based on such prediction, decision for example could be made to alter the soil's alkalinity in order to improve and sustain the desired plant. Like inferences, predictions are based on observed events, past experiences and the mental models built up from past experiences. The nature of the science process skills *Inferring* and *Predicting* discussed suggest their importance in understanding the world around us. Therefore, if the emphasis of the WASSCE Chemistry Paper 2 is on 'Application of Knowledge', then it is expected that more prominence is given to the basic science process skills of *Inferring* and

Predicting. This assertion is crucial because these science process skills assist students to interact with the environment effectively leading to better understanding of their immediate environment. Thus students will be better equipped to achieve some aspect of socio-cultural-based scientific literacy.

The last two science process skills in order of prominence in WASSCE Chemistry Paper 2 assessments from 2012 to 2016 are *Drawing* (6, 1.9%) and *Classifying* (2, 0.6%). Whereas *Drawing* appeared in all the years except 2012, *Classifying* appeared in only 2012 and 2016. Though *Drawing* is a form of communication where one's view on objects and specimens are clearly presented and labelled, MoE (2010) identified it as separate science process skill to be acquired by students. The science process skill, *Classifying* however, involves sorting objects or phenomena into groups based on their observations. This skill imposes order based on observable similarities, differences, and interrelationships. In fact, scientists use *Classifying* science process skill to have a better understanding of different objects and events in the world. It is therefore surprising that this important skill was hardly assessed over the five year period in WASSCE Chemistry Paper 2. The chemistry syllabus is also full of Classifications. For example, elements in the periodic table are ranked into metals, semi metals and non-metals based on the property – conduction of electricity or heat. Whereas metals are observed as good conductors of heat and electricity, the intermediate group (semi-metals) are classified neither good nor bad conductors with the lower rank being bad conductors of the same property. This type of classification which is based on ranking is referred to as simple serial ordering. There is also binary grouping in chemistry where objects or events are identified on basis of whether each object has or does not have a particular property. Example is acids and bases in chemistry. The ability of these substances to either change blue litmus paper to red; or change the red litmus to blue permits such binary classification. The science process skill *Classifying* also imposes order in multistage. For example, halogens are different from all other groups by having seven electrons on their outer shells. More observations based on their physical states separate fluorine and chlorine into halogens that are gases and bromine being liquid and the others being placed into solid category. Table 10 shows that six out of the nine basic science process skills identified or inferred from the chemistry syllabus for SHS level (MoE, 2010) were assessed by WASSCE Chemistry Paper 2 from 2012 to 2016. These six basic science process skills were assessed 276 times representing 87.9% of all science process skills identified over the stated period. The remaining 12.1% is taken up by *Interpreting* and *Experimenting* science process skill (Table 7).

Table 7: Integrated Science Process Skills in WASSCE Chemistry Paper 2 from 2012 to 2016

Year	Inter	Experi	Mani	Hypo	Invest	Total
2012	10	0	0	0	0	10(3.2)
2013	12	0	0	0	0	12(3.8)
2014	4	1	0	0	0	5(1.6)
2015	4	0	0	0	0	4(1.3)
2016	7	0	0	0	0	7(2.2)
TOT	**37(11.8)**	**1(0.3)**	**0(0)**	**0(0)**	**0(0)**	**38(12.1)**

Author's Construct, 2019

Inter = interpreting; Experi = Experimenting; Mani = Manipulation; Hypo = Hypothesising; Invest = Investigating

Table 7 shows that *Interpreting* and *Experimenting* science process skills are the only integrated science process skills assessed in the WASSCE

Chemistry Paper 2 from 2012 to 2016. The prominence of basic science process skills over integrated science process skills in secondary school education is consistent with similar research findings (Ongowo & Indoshi, 2013; Akinbobola & Afolabi 2010). Whereas Ongowa and Indoshi (2013) found that Kenya Certificate of Secondary Education (KCSE) biology practical examinations in Kenya for a period of 10 years (2002- 2012) consist of 73.73% basic science process skills, Akinbobola and Afolabi (2010) discovered that West African Senior Secondary School Certificate physics practical examinations in Nigeria for the periods of 10 years (1998-2007) comprised 62.8%. The finding in the WASSCE Chemistry Paper 2 over the five years in this study however appeared relatively high. The reason may be that unlike the WASSCE Chemistry Paper 2, the two examples are both practical papers.

Basic and integrated science process skills in Paper 3

Table 8 shows the science process skills in the practical paper.

Table 8: Basic science process skills in WASSCE Chemistry Practical Paper from 2012 to 2016

Year		OB	ME	RE	COM	CAL	INF	PRE	DRA	CLA	TOT
	Q1	0	3	6	4	4	0	0	0	0	17
2012	Q2	5	0	15	1	0	5	0	0	0	26
	Q3	0	0	0	7	0	2	0	0	0	9
	TOT	**5**	**3**	**21**	12	**4**	7	0	0	0	52
	Q1	0	3	6	5	5	0	0	0	0	19
2013	Q2	5	0	12	1	0	4	0	0	0	22
	Q3	0	0	0	5	0	0	0	0	0	5
	TOT	**5**	**3**	**18**	11	**5**	4	0	0	0	46
	Q1	0	3	6	5	5	0	0	0	0	19
2014	Q2	6	0	17	1	0	7	0	0	0	31
	Q3	6	0	0	9	0	0	0	0	0	15
	TOT	**12**	**3**	**23**	15	**5**	7	0	0	0	65
	Q1	0	3	6	4	4	0	0	0	0	17
2015	Q2	7	0	18	1	0	7	0	0	0	33
	Q3	1	0	0	5	0	2	0	0	0	8
	TOT	**8**	**3**	**24**	10	**4**	9	0	0	0	58

2016	Q1	0	3	6	4	4	0	0	0	0	17
	Q2	5	0	15	1	0	6	0	0	0	27
	Q3	0	0	0	5	1	0	0	0	0	6
	TOT	**5**	**3**	**21**	**10**	**5**	**6**	**0**	**0**	**0**	**50**

Author's Construct, 2019

Like the Paper 2, the Paper 3 (the practical paper) also had three of the nine identified science process skills not assessed directly. The science process skills *Predicting*, *Drawing* and *Classifying* are missing in Table 8. Comparing this findings to the case of Kenya and Nigeria, (Ongowo & Indoshi, 2013 and Akinbobola & Afolabi 2010), whereas Ongowo and Indoshi (2013) had only 3 count of the skill, *Predicting* (0.89%), Akinbobola and Afolabi (2010) showed no count of *Predicting* skill. The skill of Classifying was also missing in the latter but present in the former with count of 21 representing 6.27%. This comparing seems to suggest that the skill, *Predicting* is hardly assessed in the practical papers while it appears *Classifying* skill is given significant emphasis in practical biology papers with insignificant attention in chemistry and physics practical papers. Though the science process skill, *Predicting* was inferred from the chemistry syllabus (MoE, 2010), the science process skill, *Classifying* was stated directly in the syllabus as part of the eleven stated practical and experimental skills (PES). The lack of attention given to *Classifying* skill in both WASSCE Chemistry Paper 2 and 3 in view of the fact that the skill is conspicuously stated in the syllabus is surprising. However, *Predicting* and *Inferring* skills have similarities. Both skills draw conclusions from observations and were assessed prominently in WASSCE Chemistry Paper 2 with *Inferring* skill given significant attention in WASSCE Chemistry Paper 3. The basic science process skills identified in the practical papers are *Recording*, *Communicating*, *Observing*, *Measuring*, *Inferring* and *Calculating*

(Table 8). These basic science process skills have been discussed extensively under the WASSCE Chemistry Paper 2. The Paper 2 assessed only *Interpreting* and *Experimenting* as integrated skills, however, the practical paper, WASSCE Chemistry Paper 3 tested four integrated science process skills (Table 9). These are *Interpreting*, *Experimenting*, *Manipulating* and *Investigating*.

Table 9: Integrated science process skills in WASSCE Chemistry Practical Paper (2012 to 2016)

Year		Inter	Experi	Mani	Hypo	Invest	Total
2012	Q1	0	0	3	0	1	4
	Q2	0	1	5	0	1	7
	Q3	3	0	0	0	0	3
	Total	**3**	**1**	**8**	0	**2**	14
2013	Q1	0	0	3	0	1	4
	Q2	0	1	4	0	1	6
	A3	1	0	0	0	0	1
	Total	**1**	**1**	**7**	0	**2**	11
2014	Q1	0	0	3	0	1	4
	Q2	0	0	6	0	1	7
	Q3	0	0	0	0	0	0
	Total	**0**	**0**	**9**	0	**2**	11
2015	Q1	0	0	3	0	1	4
	Q2	0	1	6	0	3	10
	Q3	1	0	0	0	0	1
	Total	**1**	**1**	**9**	0	**4**	15
2016	Q1	0	0	3	0	1	4
	Q2	0	1	5	0	1	7
	Q3	0	0	0	0	0	0
	Total	**0**	**1**	**8**	0	**2**	11

Author's Construct, 2019

The Table 10 summarises the basic and integrated science process skills in order of decreasing prominence in the WASSCE Chemistry Paper 3. The analysis in Table 10 reveals that *Recording* is rated the highest basic science process skill with frequency of 107 (32.13%) followed by

Communicating with frequency of 58 (17.42%). The skill of *Observing* was the third in line of prominence with frequency of 35 (10.51%) followed by *Inferring* (33, 9.91%), *Calculating* (23, 6.91%) and *Measuring* (15, 4.50) being least rated basic science process skill in WASSCE Chemistry Paper 3 (2012-2016).

Table 10: Summary of basic and integrated science process skills in WASSCE Chemistry Paper 3

S/N	Basic skills	F	%	S/N	Integrated skills	F	%
1	Recording	107	32.13	1	Manipulating	41	12.31
2	Communicating	58	17.42	2	Investigating	12	3.60
3	Observing	35	10.51	3	Interpreting	5	1.50
4	Inferring	33	9.91	4	Experimenting	4	1.20
5	Calculating	23	6.91		Total	62	18.62
6	Measuring	15	4.50				
	Total	**271**	**81.38**				

Author's Construct, 2019

Though the findings in this study is consistent generally with other findings in terms of the emphasis in basic science process skills, the study observed that the emphasis placed in a particular basic science process skill differs in biology, physics and chemistry practical papers. For example, this study and Akinbobola and Afolabi (2010) rated *Recording* and *Communicating* as the ultimate and the penultimate basic science process skills however, whereas this study rated these science process skills in terms of the most prominent skills, the latter rated them in terms of the least prominent skills. Nevertheless, Ongowo and Indoshi (2013) rated *Observing* and *Communicating* basic science process skills in terms of most prominent science process skills.

The Table 10 also reveals that the top two integrated science process skills are *Manipulating* and *Investigating* with frequencies 41(12.31%) and 12

(3.6%). However, Akinbobola and Afolabi (2010) rated *Manipulating* and *Experimenting* as the top two integrated science process skills. The prominence given to *Manipulating* science process skills indicates a shift from teacher-centred to child-centred approach to teaching and learning. This shift implied that students are now given more opportunity to engage in problem solving, discovery and hands-on-activities learning. The approach has the tendency to help students develop appropriate skills, abilities and competencies. However, comparing the frequencies of *Manipulating* (41) to that of *Interpreting* (5) recorded within the period (2012 to 2016) creates room for concern. It is expected that if the frequency of *Manipulating* science process skill matches that of *Interpreting* science process skill, then it can be inferred that students are given the opportunity to evaluate and interpret data emerging from such manipulating activities. The mismatch however suggests overemphasis on *Manipulating* science process skill. Overemphasis in manipulative skills however is said to prevent students from engaging in useful discussion that brings about meaningful learning (Abrahams & Millar, 2008). Osborne (2015) doubts the usefulness of the skills developed via manipulation at the secondary school laboratories by stating that manipulating skills ‘developed with the scientific instrumentation available in the standard school laboratory are not, given the significant difference in instrumentation, necessarily the same as needed in a university laboratory or the workplace’ (Osborne, 2015, p. 20). However, the motivation and interest which students derived from manipulating materials and equipment during the learning process cannot be over-ruled.

It is also observed that while this study rated *Investigating* science process skill above *Experimenting* science process skill, Akinbobola and Afolabi (2010) rated *Experimenting* science process skills higher than *Investigating* science process skill. In chemistry emphasis is placed in analysing contents of sample in term of quality and quantity while physics practical assessments tend to control variables to observe and record the effect of the change. Typical example in electricity (physics) is changing the resistant in a circuit and recording the effect on voltage. These two science process skills are crucial and widely used by professional scientists. For example, medical laboratory and forensic scientists use investigation widely by following established procedures and agreed reagents while frontier scientists usually explore factors and procedures through experimentations. It is worth noting that the example in biology practical paper (Ongowo & Indoshi, 2013) indicates that the *Manipulating* science process skill is missing in the identified integrated science process skill with *Experimenting* and *Interpreting* science process skills occupying the top two positions in terms of the most prominence integrated science process skills. These evidences show different emphasis in the education of the three pure sciences at the secondary school level.

Contributions of the items in Questions 1, 2 and 3 (Q1, Q2 and Q3) in the WASSCE Chemistry Paper 3 for the basic and integrated science process skills

Table 11 indicates the science process skills assessed by the various questions in the practical paper. Science education like medical field regularly diagnoses problems and offers prognosis to help mitigate them. This study identified a possible reason for the chief examiners' persistent report of poor performance in WASSCE Chemistry Paper 3.

Table 11: Basic and interested science process skills in WASSCE Chemistry Paper 3 (2012-2016)

S/N	Basic skills	Q 1	Q 2	Q 3	S/N	Integrated skills	Q 1	Q2	Q 3
1	Recording	30	77	0	1	Manipulating	15	26	0
2	Communicating	22	5	31	2	Investigating	5	7	0
3	Observing	0	28	7	3	Interpreting	0	0	5
4	Inferring	0	29	4	4	Experimenting	0	4	0
5	Calculating	22	0	1		Total	20	37	5
6	Measuring	15	0	0					
	Total	**89**	**139**	**43**					

Author's Construct, 2019

The Table 11 and Figures 14 and 15 show that the science process skills assessed by the items in Q1 are *Recording*, *Communicating*, *Calculating*, *Measuring*, *Manipulating* and *Investigating*. The science process skills assessed in Q2 also are *Recording*, *Communicating*, *Observing*, *inferring*, *Manipulating*, *Investigating* and *Experimenting*.

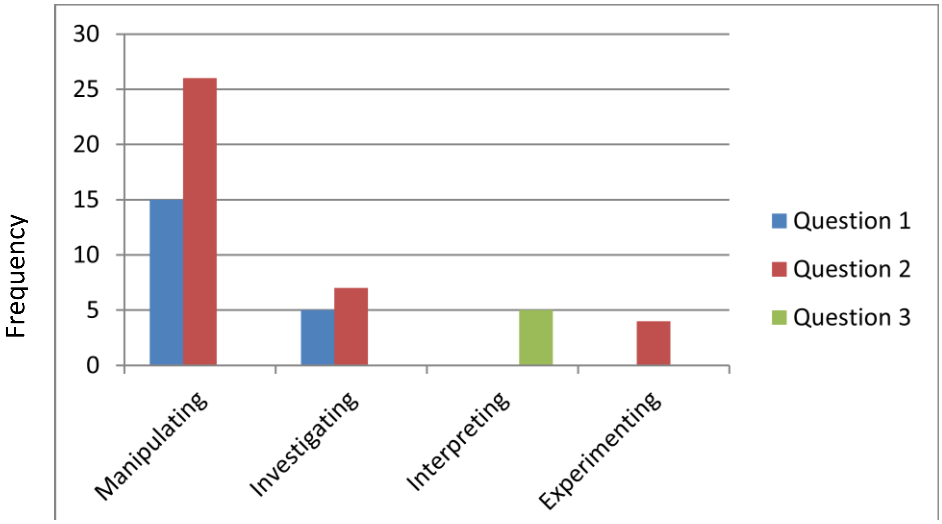


Figure 16: Integrated science process skills in WASSCE Chemistry Paper 3 (2012 to 2016) (Author's Construct, 2019)

Both Q1 and Q2 had four basic skills but Q2 had three integrated skills with Q1 having two integrated skills. Like the Q1, the Q3 also had four basic science process skills (*Communicating*, *Observing*, *Inferring* and *calculating)* but with only one integrated science process skills (*Interpreting)*. The thinking operation schema associated with basic science process skills is known to be concrete stage while integrated science process skills require formal operation thinking (Ongowo & Indoshi, 2013). In term of quality, one may conclude that the Q2 would be relatively more complex and difficult to handle since Q2 had more integrated science process skills. Also considering the occurrences of the science process skills in each question from 2012 to 2016, the items in Q2 assessed the highest number of science process skills in both basic science process skills (139) and integrated science process skill (37) followed by the items in Q1 with basic science process skill (89) and integrated science process skills (20). The items in Q3 assessed 43 basic science process skills and 5 integrated science process skills. These findings support the initial analysis on the Chief examiners' comments that suggest that the performances of students during WASSCE Chemistry Paper 3 from 2012 to 2016 on Q1 and Q3 were both slightly above average but that of the Q2 were below average. This finding in the study suggests that the cause of students' abysmal performance in the practical chemistry paper is rooted in the nature of the Q2 in the WASSCE Chemistry Paper 3. The Figure 16 gives visual differences in the WASSCE Chemistry Paper 3.

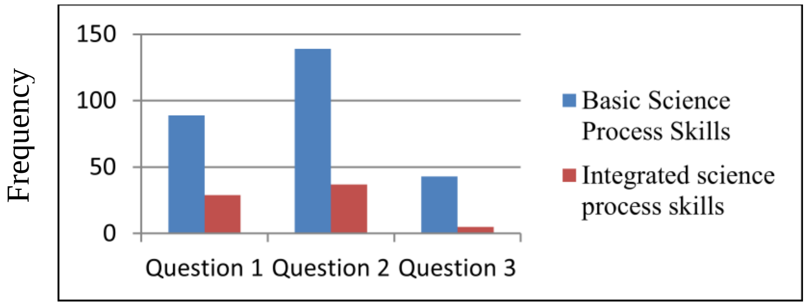


Figure 17: **Science process skills in WASSCE Chemistry Paper 3 questions (2012-2016) (Author's construct, 2019)**

Summary of basic and integrated science process skills in WASSCE Chemistry Papers 2 & 3

The summary of the science process skills in the two WAEC papers (Table 7) shows about 85% commitment to developing nine basic science process skills with 15% dedicated to developing four integrated science process skills. The top 5 prominent science process skills (Table 12) are all basic science process skills (*communicating*, *Recording*, *Calculating*, *Observing* and *Inferring*). The emphasis in the basic science process skills seems to be targeted to strengthen the gains at the basic school level to provide solid grounds for higher order intellectual skills.

Table 12: Summary of basic and integrated science process skills in WASSCE Chemistry Paper 2 & 3

S/N	Basic skills	F	%	S/N	Integrated skills	F	%
1	Communicating	255	38.12	1	Interpreting	42	6.28
2	Recording	107	15.99	2	Manipulating	41	6.13
3	Calculating	58	8.67	3	Investigating	12	1.79
4	Observing	57	8.52	4	Experimenting	5	0.75
5	Inferring	57	8.52		Total	100	14.95
6	Measuring	15	2.24				
7	Predicting	12	1.79				
8	Drawing	6	0.90				
9	Classifying	2	0.30				
	Total	**569**	**85.05**				

Author’s Construct, 2019

The basic science process skills are associated with the ability to perform empirical inductive reasoning or piagetian concrete operational reasoning (Ongowo & Indoshi, 2013). Thus the basic science process skills are mostly applied appropriately in natural science through scientific inquiry to equip pupils to order and describe natural objects and events (Brotherton & Preece, 1995; Sevilay, 2011) at the primary level. The age range of senior high school level students in Ghana is 14 to 17 years. This set the proportion of the students’ population at the senior high school level to reach formal reasoning to at least 30% to 34% (Monk, 1990; Shayer & Adey, 1981). The 15% consideration given to the integrated science process skills in the WASSCE Chemistry papers does not commensurate the expected proportion at the SHS level and therefore considered low. Though the basic science process skills are easy to learn and can be transferred to the immediate environment to understand nature, integrated science process skills are crucial to help identify and formulate solutions to everyday scientific problems (Akinbobola & Afolabi, 2010; Ongowo & Indoshi, 2013). The evidence adduced therefore does not meet MoE's (2010, p. vii) expectation for students to '…acquire the capacity for practical and experimental skills that are needed for scientific problem solving'. The frequencies observed for the integrated science process skill, *Interpreting* were recorded from mainly analysis and interpretations of concepts and laboratory practices under the theory paper 2 and the Question 3 aspect of the practical paper 3. This observation implied that students are not given the opportunity to evaluate and interpret the data obtained from using the *Manipulating* skills observed in the study. The mismatch between *Manipulating* and *Interpreting* skills limits further the effective used of the observed 15% integrated science process skills obtained to prepare students to solve problems scientifically.

Opportunities given to Students to help them develop Science Process Skills

Research question 2 sought to find out opportunities given to students to help them develop science process skills in school.

WAEC is the assessment body responsible for determining the summative influence of the opportunities given to students to acquire science process skills by the chemistry syllabus. Table 13 therefore compares science process skills assessed by WASSCE Papers 2 & 3 to science process skills contained in the specific objectives of the chemistry syllabus.

Table 13: Science process skills in WASSCE Papers 2 & 3 (2012-2016) versus specific objectives in Ghanaian chemistry syllabus (2010)

		WASSCE Papers 2 & 3		MoE Specific Objectives	
S/N	**Basic Skills**	**F**	**%**	**F**	**%**
1	Communicating	255	38.12	128	51.61
2	Recording	107	15.99	0	0.00
3	Calculating	58	8.67	5	2.02
4	Observing	57	8.52	0	0.00
5	Inferring	57	8.52	28	11.29
6	Measuring	15	2.24	1	0.40
7	Predicting	12	1.79	0	0.00
8	Drawing	6	0.90	3	1.21
9	Classifying	2	0.30	4	1.61
	Total	**569**	**85.05**	**169**	**68.15**
	Integrated Skills				
1	Interpreting	42	6.28	57	22.98
2	Manipulating	41	6.13	5	2.02
3	Investigating	12	1.79	3	1.21
4	Experimenting	5	0.75	14	5.65
	Total	**100**	**14.95**	**79**	**31.85**

Author’s Construct, 2019

MoE (2010, vi) expects teachers to individualise instruction to the level of the students ‘as much as possible such that the majority of students will be able to master the objectives of each unit of the syllabus’. The analysis in Table 13 shows that strict adherence to the specific objectives of the chemistry syllabus enables students to acquire 51.61% *Communicating* skill as proportion of the entire science process skills available to the students in the specific objectives. This percentage of *Communicating* skill offered to students by the syllabus is higher than the percentage of the same skill assessed by WASSCE Chemistry Paper 2 & 3. The skill of *communicating* usually consists of presentation of acquired scientific concepts and ideas in the form of defining, describing, stating and listing. The higher demands on students to communicate scientific concepts as evidence of acquisition of scientific concepts may emanates from the view that science education is not to create new knowledge, but rather to help students understand a body of existing, consensually agreed and well-established knowledge (Osborne, 2015). Science is also seen as culture (Aikenhead, 2008) and adherents of science culture sometimes insist on preserving this culture with strict attention paid to specificity with respect to how concepts are defined and described. It is therefore not surprising that the chemistry syllabus devotes such high prominence to students to rehearse scientific ideas in the form of communicating scientific ideas as part of their enculturation process (Aikenhead, 2008).

Unlike the WASSCE Chemistry Papers which has the top four prominent science process skills (*Communicating*, *Recording*, *Calculating* and *Inferring*) being basic science process skills, the specific objectives offer two basic and two integrated science process skills (*Communicating*, *Interpreting*, *Inferring*, *Experimenting*) as the top four prominent skills. Research reports that focus on learning with intention to understanding indicates that the ability to 'remember information' in deep learning (learning with understanding) situation is an unintentional by-product (Gibbs, 1981). The evidence in this analysis however shows that the specific objectives of the chemistry syllabus emphasise and provide opportunity for students to rehearse scientific ideas with the view to understand the ideas as well as acquiring higher order skills. This emphasis to sharpen students' ability to recall information suggests that the chemistry syllabus expects or assumes Memorising with Understanding learning approach for students (Kember, 1996). This expectation or assumption appears to perhaps emanate from: (1) the nature of the WAEC assessment and (2) the nature of the Specific objective of the syllabus. This learning approach which has been identified mainly in Asian countries is characterised with systematic, step-by-step approach to understanding study materials and also to commit materials into memory for reproduction. The reason for the reproduction is to pass high stake examinations which test mainly recall knowledge. This approach however has been described as narrow orientation by Kember and Gow (1990). The evidence adduced in this study shows that the WAEC WASSCE Chemistry examination is prominent in emphasising recall knowledge in the form of communicating scientific ideas. This evidence justifies possible assumption by the framers of the chemistry syllabus for the 'Memorising with Understanding' approach to learning. Secondly, the Author's analysis by mapping the Specific objectives of the chemistry syllabus unto the profile dimension reveals 81% Knowledge and Understanding, 2% Application of Knowledge and 17% Practical and Experimenting Skills. This implies that majority of the Specific objectives are situated in abstract contexts outside the experience of the learners with little opportunity to apply knowledge in new authentic everyday situations. This approach lacks embodiment. Embodied learning embraces reasoning, perception, cultural tool and active participation in the learning process (Hill & Smith, 2005). The approach of engaging learning of relevant concepts in a common and familiar context embodies learning to provide mediation tool to construct meaningful learning. The lack thereof usually is memorisation of knowledge. Being aware, the framers seem to appreciate the need for the capacity to recall hence the opportunity to provide emphasised rehearsal of ideas in the form of *Communicating* skill.

Another distinguishing feature of the specific objectives from the WASSCE Chemistry Paper 2 & 3 is that unlike the latter they commensurate the proportion of students required to access basic science process skills and integrated science process skills. The analysis in Table 13 shows that 68.15% of the specific objectives enable students to master basic science process skills while the remaining 31.85% exposes students to the acquisition of integrated science process skills. The framers of the specific objectives seem to take cognisance of the research evidence that about 30% to 34% of 14 -17 year olds are able to access formal reasoning (Monk, 1990; Shayer & Adey, 1981) to acquire integrated science process skills. The evidence discussed indicates that the WAEC assessment in WASSCE Chemistry Papers 2 & 3 reflects the opportunities given to students in emphasising on communicating skills, however the assessment papers stress more on the basic science process skills and disproportionally assesses less of the opportunities given to students in term of the integrated science process skills. Table 14 and 15 show how students and teacher ranked selected activities they claimed help them to develop science process skills and to solve scientific problems.

Table 14: Students' ranking of some activities used to help develop science process skills (N = 905).

Rank	**5**	**4**	**3**	**2**	**1**	
	F (%)	**F (%)**	**F (%)**	**F (%)**	**F (%)**	**N (%)**
Reading	141 (15.8)	201(22.5)	325 (36.4)	156 (17.5)	70 (7.4)	893 (98.7)
Talking	88 (10.0)	275 (31.3)	262 (29.8)	186 (21.2)	67 (7.6)	878 (97.0)
Doing	107 (12.1)	181(20.4)	299 (33.7)	221 (24.9)	78 (8.8)	886 (97.9)
Field Trip	46 (5.3)	74 (8.4)	140 (16.0)	264 (30.1)	352 (40.2)	876 (97.8)
Writing	77 (9.2)	118 (14.0)	174 (20.7)	227 (27.0)	244 (29.0)	840 (92.8)
Project	118 (13.5)	212 (24.2)	261(29.8)	191 (21.8)	93(10.6)	875 (96.7)
Case	89 (10.5)	113 (13.3)	208(24.5)	203 (23.9)	235 (27.7)	848 (93.7)
Symbolism	123 (14.3)	144 (16.7)	189 (22.0)	193 (22.4)	211 (25.00	860 (95.0)
N (%)	**794 (11.4)**	**1322 (19.0)**	**1861 (26.8)**	**1643(23.6)**	**1351(19.4)**	**6956 (96.1)**

Author's Construct, 2019

5 = Always; 4 = most of the time; 3 = some of the time; 2 = not quite often 1= never engage in it

The student respondents were 905, however the analysis in Table 17 shows that none of the activities attracted 100% ranking. For example, 893 students (out of 905) ranked 'Reading scientific books and journals' (98.7%). Science process skills are dependents on scientific concepts and the context in which they are applied (Harlen, 1999). For instance, in order to infer that the gas released from adding acid to a particular rock sample is carbon dioxide, one should know about the context (for example, the rock containing carbonates) and the theory concerning reaction of acid with carbonate. Knowledge of the concept and context in which a skill is applied are therefore crucial for successful use of the skill. One of the major means of acquiring scientific concepts and the context in which they are applied is reading science books and journals. The ranking of 5 and 4 represent 'always and most of the time' respectively. Selection of ‘always and most of the time’ therefore indicates regular activities.

Table 15: Teachers’ ranking of some activities used to help develop science process skills (N = 85)

Rank	**5** **F (%)**	**4** **F (%)**	**3** **F (%)**	**2** **F (%)**	**1** **F (%)**	**N (%)**
Reading	12 (14.1)	50 (58.8)	23 (27.1)	0 (0)	0 (0)	85 (100)
Talking	46 (54.1)	33 (38.8)	6 (7.1)	0 (0)	0 (0)	85 (100)
Doing	20 (23.5)	33 (38.8)	26 (30.6)	6 (7.1)	0 (0)	85 (100)
Field Trip	0 (0)	22 (25.9)	16 (18.8)	39 (45.9)	8 (9.4)	85 (100)
Writing	6 (7.4)	20 (24.7)	24 (29.6)	23 (28.4)	8 (8.9)	81 (95.3)
Project	6 (17.1)	24 (28.2)	32 (37.6)	23 (27.1)	0 (0)	85 (100)
Case	0 (0)	12 (14.8)	28 (34.6)	37 (45.7)	4 (4.9)	81 (100)
Symbolism	26 (30.6)	26 (30.6)	19 (22.4)	10 (11.8)	4 (4.7)	85 (100)
N (%)	**116 (17.3)**	**220 (32.7)**	**174 (25.9)**	**138 (20.5)**	**24 (3.6)**	**672 (98.8)**

Author’s Construct, 2019

5 = Always; 4 = most of the time; 3 = some of the time; 2 = not quite often 1= never engage in it

The analysis in Table 14 indicates that 342 students representing 38.3% of those who ranked ‘Reading scientific books and journals’ have regular habit of reading science information outside the teachers’ notes. The teacher respondents (Table 15) however showed higher percentage of regular interest in reading about science. The Tables 15 shows that 62 teachers representing 72.9% of those who ranked ‘Reading scientific books and journals’ have regular habit of reading about science. Both teachers and students read to enrich their knowledge about scientific concepts but also reading enables one to become aware of the science process skills and how they are applied successfully. Good teachers read regularly to enable them prepare effective lessons. It is therefore heart-warming to know that about more than 70% of teachers at the SHS level are cultivating the right habit with respect to reading about science. The ranking of 3 ‘some of the time’ indicates that reading is not a regular habit but is used occasionally. Some students occasionally go to the library to read science books outside the prescribed texts and teacher’s note to either help them answer assignments/projects or seek further information to understand concepts taught in class. The report shows that 325 students representing 36.4% are in this category and so are the remaining 23 teachers (27.1%). These teachers in this category are those who usually have prepared notes which they use to teach. However, they occasionally read about science to update their notes. There are also 220 students who hardly read about science outside the prepared teachers’ note. These students may depend on other activities to develop science process skills.

‘Talking, discussing and debating scientific issues’ are also means to develop science process skills. The analysis shows that 361 students (41.3%) regularly engage in this activity, with 262 (29.8%) practicing this activity occasionally. However, 253 students (28.9%) hardly got the opportunity to practice this activity (Tables 14). Chi (2009) gave evidence that students who talked, discussed and debated ideas (emanating from data) performed better than those who merely produced a written report. The group of students who gave written report also outperformed students who were just active. Those who talked and discussed outperformed the other groups because by talking and discussing, they practiced how to link up concepts, theories and data (evidence). Scientific talks and debates are not merely communicating scientific ideas but also involve collecting data, evaluating evidence and mounting cogent argument based on the available data. Practising this activity in schools will not only help students to develop the basic science process skills but also the higher order integrated science process skills as well. All of the teacher respondents seem to realise this important scientific activity of talking, discussing and debating issues. The evidence shows that 92.9% (79) of the teachers engage in this activity regularly with the remaining 7.1% (6) practising the activity occasionally. Aside, some schools having debate clubs that regularly (but some occasionally) talk, discuss and debate science issues, the activity is also classroom based. The use of this activity in the classroom shifts teaching and learning away from teacher centeredness toward child centeredness. The evidence adduced suggests that though majority of Ghanaian chemistry students experience some form of active learning, significant number of them 253 (28.8%) receive science education through transmission of knowledge or engage in active handling and operation of materials and equipment without the opportunity to discuss the data derived from such activities. Such approaches are not efficient in assisting the development of science process skills.

The next activity, 'doing laboratory work' is perceived as a major means to develop science process skills (Abrahams & Millar, 2008; Ornstein 2006; Ampiah, 2004). Ampiah (2004) assert that practical activities were usually not organized regularly for Ghanaian students in their first two years but practical activities become regular in their third year. These findings seem to reflect in the experience of 288 (32.5%) students who indicated regular experience of doing laboratory work. The percentage of teachers who showed regular experience of laboratory work was 62.3% (53) with 30.6% (26)

occasionally experiencing laboratory work leaving only 7.1% (6) indicating that they hardly have the opportunity to partake in this activity. However, students who occasionally experience the activity were 299 (33.7%) showing that 66.2% of the students covered at least had occasional experience of doing laboratory work. This percentage (66.2%) does not commensurate that of teachers (92.9%) that claim to at least have had occasional experience of doing laboratory work. This evidence suggests that significant number of teachers' experience of laboratory works were teacher demonstrations. This teacher centred activity though is found to help confirm theories, hardly help students to develop science process skills (Ampiah, 2004; Banchi & Bell, 2008) particularly those involve in designing experiments and manipulations of equipment and materials. However, demonstrations can be used to develop skills like inferring, predicting as well as data evaluating and interpreting by discussing data carefully collected by teachers. The analysis in Tables (14 & 15) also reveal that more than one out of three of the student respondents showed they hardly experience doing laboratory work but less than one out of ten teachers had the same experience. This lack of opportunity to do laboratory work may be explained either due to lack of laboratory facilities or merely due to some teachers' perception (perhaps, the 7.1%) that laboratory work is not needed in order to be successful in WAEC examinations. For the former reason, it is known that significant number of Ghanaian SHS schools referred to as satellite schools do not have laboratory facilities and depend on Science Resource Centres (Ampiah, 2004) for their experience of doing laboratory work. This situation comes with several challenges in such schools forcing some of them to have occasional experience of laboratory work with others avoiding the entire opportunity to access such facilities. The latter reason however is mainly based on anecdotal experience where significant number of teachers depends on WAEC confidential reports to coach their final year students. Experience shows that some students successfully write the WAEC chemistry practical examinations without handling the samples nor the equipment provided during such examinations.

Students are also expected to 'write about science'. In fact, reporting is part of the 11 science process skills stated in the MoE (2010). Scientific writing is a major means of communicating and arguing one's ideas and research findings. Assisting students to write about science therefore not only improve students' ability to communicate science but also to improve how to interpret data in an argumentative manner. Most students at the SHS level write about science in the form of reporting on laboratory experiments or writing scientific articles in school science magazines or simply writing scripts for scientific debates in science debate clubs. The analysis in the Table 14 shows that 43.9% of the student respondents indicated that they have at least occasionally written about science. This percentage fall short of 66.2% of the respondents that indicated that they have at least occasionally done laboratory work. The evidence supports the assertion that significant numbers of students' experience of practical work are teacher demonstrations. Usually, students are not expected to report on teacher demonstrations but are expected to do so during active participations of laboratory activities. Also while the Tables 15 shows that 92.9% of the teacher respondents indicated having at least occasional experience of doing laboratory work, only 61.7% of them indicated having at least occasional experience of writing about science. This evidence is not surprising because teachers are not expected to write report after experiments. They may however write scientific articles to express their opinions or scientific findings.

Another way of communicating science is representing scientific ideas using symbols and mathematics. The use of symbols and mathematics is one of the major tools scientists use to represent the world and to engage in deductive reasoning (Osborne, 2015). Using symbols and mathematics helps in developing science process skills like inferring, predicting and interpreting scientific data. The number of the student respondents indicating using the activity at least occasionally was 456 students (53%) and that of teacher being 71 teachers representing 83.6%. It is however surprising that 47% and 16.5% of students and teachers respectively claimed they hardly experience representing scientific ideas using symbols and mathematics. Science, particularly chemistry is full of symbols and mathematical formulae and models. This category of respondents may be having misconception of the nature of science. For some people, science is remotely outside them. Science perhaps, to them, belongs to the Einstein, Newton and the big names. They may have the view that using and reading scientific ideas are within their capabilities but discovering and creating scientific ideas are outside their capacity. Therefore, representing science with symbols, models and mathematics are outside their purview. The four activities: (1) reading scientific books and journals; (2) talking, discussing and debating scientific issue; (3) writing about science; and (4) representing scientific ideas using symbols and mathematics are set of literate activities (Osborne, 2015). These activities not only build students to understand scientific concepts but also help them to link up ideas to develop science process skills.

The last three activities to be discussed usually help students to develop science process skills by identifying authentic problems and finding solutions for them. These are projects, case studies and field trips (MoE, 2010). The analysis in Table 14 shows that the percentages of students who accessed project activity regularly, occasionally or hardly had the opportunity to access the activity are 37.7% (330), 29.8% (261) and 32.4% (284) respectively. The corresponding percentages of teachers who ranked the same activity are 35.3% (30); 37.6% (32) and 27.1% (23) respectively. This evidence shows that higher proportion of teachers had at least occasional experience of project activity than that of students. This observation can be explained by the fact that teachers usually have other projects (science projects for higher studies or taking advantage of their laboratory facilities to research into individual interest and preparation for lessons), aside supervising students' projects. The proportions of teachers (27.1%) and students (32.4%) that hardly engage in project activity however, are lower than that of teachers (50.6%) and students (51.6%) who hardly engage in case studies. This shows that the use of project work is more popular at the SHS level than the use of case studies. Case is a project set in authentic real life context with specific purpose but is unique for being narration of situations, data sampling or statements that present unresolved issues or provoke questions (Schwartz, 2014). Case can be used purposefully to develop specific science process skills including inferring, predicting, communicating and interpreting skills. The use of case studies in medical and accountancy education for transfer and development of skills is very common. It is therefore unfortunate that more than 50% of both teachers and students hardly access this opportunity to develop science process skills. The situation is even worst when field trip activity is considered. The analysis shows that 55.3% of teachers and 70.3% of students hardly partake in field trips. A field trip can be any teaching and learning excursion outside of the classroom. A field trip provides authentic learning experience by connecting reality and theory. This connection of reality with theory provides opportunity to practice the science process skills. A well planned field trip can be purposeful project or case to develop particular science process skills. The findings in this report indicate that field trip is the least patronage opportunity among the eight activities examined. The low patronage of field trips may be due to its associated challenges. For example, each trip affects the entire school timetable since field trips usually take longer time than the durations assigned to each subject. There are other issues like finance and planning. Based on their nature, the last three activities are put under problem solving activity.

Summary of opportunities to develop students' science process skills

The specific objectives of the chemistry syllabus have been shown to help develop directly eleven out of the fourteen science process skills identified in the chemistry syllabus. The emphasis of the specific objectives is mainly to help students to communicate scientific ideas with proportionate opportunity to develop the higher order integrated science process skills. The other opportunities available to help students develop science process skills are however categorised into three activities. These are: (1) Literacy Activity comprising reading scientific books and journals; talking, discussing and debating scientific issues; writing about science; and representing scientific ideas using symbols and mathematics; (2) Laboratory Activity; and (3) Problem Solving Activity consisting of projects; case studies; and field trips. The proportions of teachers and students ranking the three opportunities are shown by the Table 16, and Figures 17 and 18.

Table 16: Respondents' ranking of the three opportunities to develop science process skill

Rank	Literacy Activity		Laboratory Activity		Problem Solving Activity	
	Students	Teachers	Students	Teachers	Students	Teachers
Regularly	33.6	63.8	32.5	62.4	25.1	25.5
Occasionally	27.4	23.0	33.7	30.6	23.4	30.3
Hardly	39.0	13.1	33.7	7.1	51.5	44.2

Author's Construct, 2019

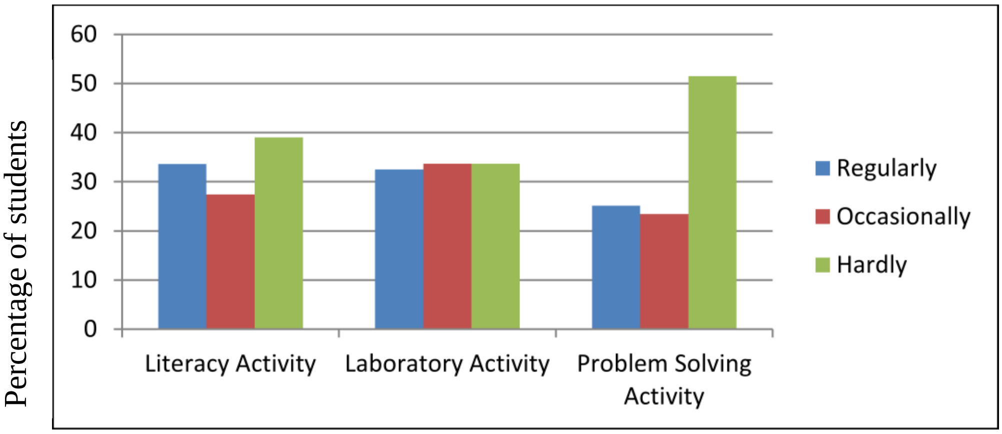


Figure18: **Percentage of students ranking the three opportunities to develop science process skills (Author's construct, 2019)**

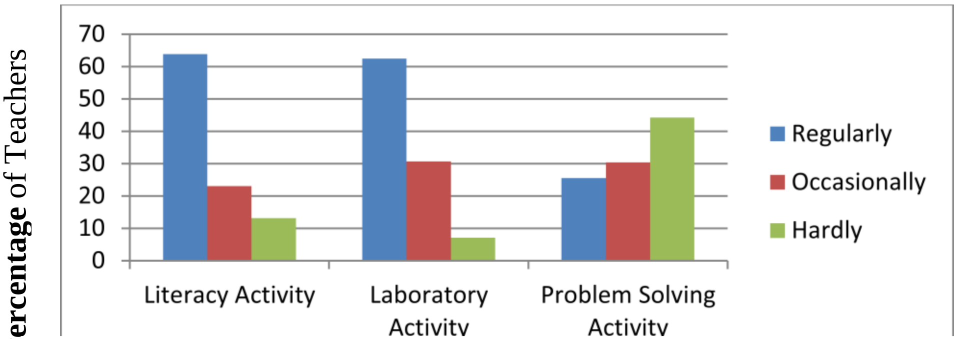


Figure 19: **Percentage of teachers ranking the three opportunities to develop science process skills (Author's construct, 2019)**

The analysis shows that though, the proportions of teachers accessing the three opportunities regularly are higher than that of students, the trend is similar. The proportions decrease in the order of Literacy Activity, Laboratory Activity and Problem Solving Activity for both teachers and students. Similarly, the proportions of those who hardly had the opportunity to access the activities increase in the order of Laboratory Activity, Literacy Activity and Problem Solving Activity for both teachers and students. The synergic effect of the observable trends in the analysis is contained in the Table 17 and Figure 20

Table 17: Ranking of the three opportunities to develop science process skills

	Laboratory Activity	**Literacy Activity**	**Problem Solving Activity**
Teachers	3.8	3.5	2.8
Students	3.0	2.7	2.3

Author's Construct, 2019

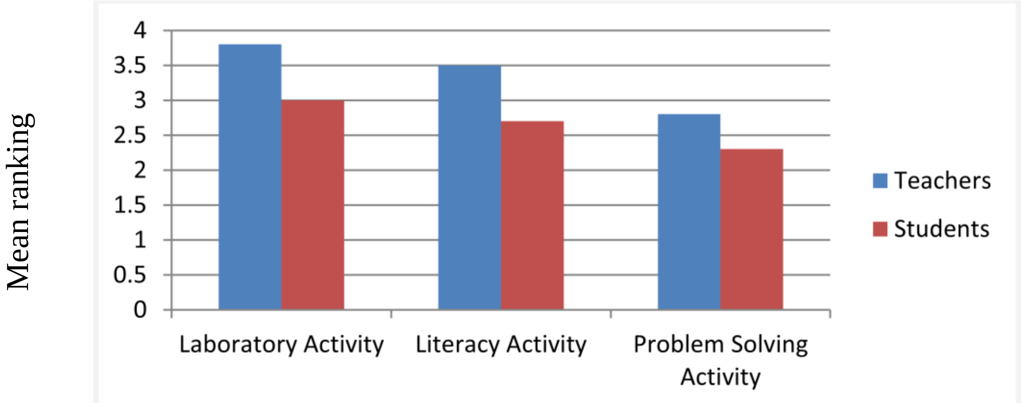


Figure 20: **Ranking of the three opportunities to develop science process Skills (Author's construct, 2019)**

The ranking of teachers collaborates that of students to state, that the most common activity to develop science process skills in Ghanaian SHS level is Laboratory Activity, follow by Literacy Activity with Problem Solving Activity being the least accessed. The evidence in the analysis shows that both teachers and students fall short of making any of the opportunities to develop science process skills a regular activity. This is shown by all the three activities having rank score of below 4 which is the lowest point for obtaining regular score for both teachers and students. Even teachers who usually teach multiple classes fall short of having any of the activities as a regular event. MoE (2010) expects practical activities to be regular feature in the SHS chemistry teaching and learning by assigning 2 out of every 6 chemistry lesson to be practical lesson. However, neither laboratory Activity nor Problem Solving Activity comes close to being regular activity. Perhaps, teachers and students spend more time of their teaching and learning to satisfy WAEC examinations rather than developing science process skills and concepts that prepare students for future scientific challenges.

SHS Chemistry Teachers' and Students' Perceptions on the Development of Science Process Skills

Research question 3 sought to find out SHS chemistry teachers and students' views on the development of science process skills.

Tables 18 and 19 contain analysis on teachers and students' ranking of scientific concepts, science process skills and scientific attitudes. Science process skills are needed to link up and organise scientific concepts. For example, new data are linked to established theories through the skills of inferring and interpreting. This implies that science process skills depend on concepts. Also, scientists' attitudes toward how knowledge is pursued, is based on respect and interpretation, which are crucial to developing the science process skills that links up scientific concepts.

Table 18: Students' perceived importance of scientific concepts, science process skills and scientific attitudes (N=905)

Rank	VI	IM	MI	LI	UM	
	F (%)	F (%)	F (%)	F (%)	F (%)	N (%)
Scientific Concepts	746 (83.3)	106 (11.8)	24 (2.7)	10 (1.1)	10 (1.1)	896 (99.0)
Science Skills	529 (59.1)	279 (31.2)	60 (6.7)	16 (1.8)	11 (1.2)	895 (98.3)
Scientific Attitudes	357 (39.9)	296 (33.1)	173 (19.3)	44 (4.9)	25 (2.8)	895 (98.3)
N (%)	**1637 (60.9)**	**685 (25.5)**	**260 (9.7)**	**72 (2.7)**	**47 (1.7)**	**2686 (98.9)**

Author's Construct, 2019

VI = Very important; IM = Important; MI = Moderately important; LI = Of little important; UM = Unimportant

The views of these three aspects of science are therefore, important in developing science process skills. The analysis in Tables 18 shows that 86.4% of the student respondents believe that all the three, Scientific Concepts, Science Process Skills and Scientific Attitude are at least important (ranking 4 and 5). The proportion of teachers (Table 19) who have the same view on scientific concepts, science process skills and scientific attitudes are however, higher (95.3%).

Table 19: Teachers' ranking of the importance of scientific concepts, science process skills and scientific attitudes (N=85)

Rank	**VI** **F (%)**	**IM** **F (%)**	**MI** **F (%)**	**LI** **F (%)**	**UM** **F (%)**	**N(%)**
Scientific Concepts	62 (72.9)	23 (27.1)	0 (0)	0 (0)	0 (0)	85 (100)
Science Process Skills	32 (37.6)	49 (57.6)	4 (4.7)	0 (0)	0 (0)	85 (100)
Scientific Attitudes	14 (16.5)	63 (74.1)	8 (9.4)	0 (0)	0 (0)	85 (100)
N (%)	**108** **(42.4)**	**135** **(52.9)**	**12** **(4.7)**	**0** **(0)**	**0** **(0)**	**255** **(100)**

Author's Construct, 2019

VI = Very important; IM = Important; MI = Moderately important; LI = Of little important; UM = Unimportant

The result in Table 19 show that students and teachers had positive perception of these concepts. However, teachers are more likely to understand the nature of science and therefore, attach higher importance to these concepts. There are 4.4% of the student respondents who seems to doubt the importance of these three concepts (ranking 2 and 1). None of the teachers though had this view. The proportion of student respondents who rated scientific concepts at least, important was 95.1% with only 2.2% doubting the importance of scientific concepts. The teacher respondents however, had 100% at "least importance" for scientific concepts without any of them doubting the importance of scientific concepts. The figures show that the proportion of both teachers and students who ranked the three concepts "least important" decreased in the order: scientific concepts, science process skills and scientific attitudes.

This order reflects the importance attached to the three concepts in the chemistry syllabus. In the chemistry syllabus 70% rating is directly assigned to knowledge and understanding of scientific concepts and their applications with only 30% dedicated to science process skills and scientific attitudes in the form of practical and experimental skills (PES). The direct analysis of the scientific attitude with respect to science process skills under PES however, was scanty (MoE, 2010). The analysis in Table 20 shows that both teachers and students had strong and positive view of science process skills as well as scientific concepts and scientific attitudes.

Table 20: Respondents' ranking of scientific concepts, science process skills and scientific attitudes

	Scientific Concepts	Science process Skills	Scientific Attitudes
Teachers	4.7	4.3	4.1
Students	4.7	4.4	4.0

Author's Construct, 2019

Aside the overall views of teachers and students on science process skills, their view on the reduced factors are also reported. Table 21 shows the respondents' perceived importance of the reduced factors. Table 21 shows that critical thinking skill is the least ranked skill among the reduced variants. The ranking of teachers for critical thinking skill indicated that the skill is at least important (4.1) however, this ranking falls below the other variants, mathematics/ statistical skill (4.5), experimentation/ problem solving skill (4.3), and argumentation skill (4.2).

Table 21: Respondents' perceived importance of the reduced factors of science process skills (N= 85 for teachers, N = 905 for students)

	Critical Thinking Skills	Mathematical/ Statistical Skills	Experimentation/ Problem Solving Skills	Argumentation Skills	N
Teachers	4.1	4.5	4.3	4.2	85
Students	4.0	4.3	4.3	4.0	905
Category A	3.4	4.4	4.3	4.0	353
Category B	3.7	4.0	4.1	3.8	288
Category C	3.8	4.2	4.0	3.9	264
Mean	3.8	4.3	4.2	4.0	

Author's Construct, 2019

Similarly, students ranked critical thinking skill almost important (4.0) but the other variants were ranked at least important: mathematics/ statistical skill (4.3), experimentation/ problem solving skill (4.3), and argumentation skill (4.0). These observations are explainable due to the fact that mathematics and experiments are more common language/terms used at the SHS level than argumentation and critical thinking. It seems both teachers and students associate familiarity to importance. The analysis of data in Table 18 also shows that all the three category of schools ranked critical thinking skill almost important. The category C schools gave the highest ranking of 3.8, followed by category B schools (3.7) and then category A schools (3.4). The ranking of schools into categories by Ghana Education Service (GES) is based on both performances and facilities available to each school. Hence category A schools are generally more endowed than category B schools which also explicitly have more resources than category C schools. This evidence suggests inverse relation between resources and perceived importance of critical thinking skill. Usually, limited resources are utilised with critical planning and executions. It also suggests that less endowed schools engage in more theory and abstract based instruction (requiring more critical engagement) than the well-endowed schools that may afford resources to make the learning experience more concrete. The ranking of the respondents' perceived occurrences of the skills were relatively low generally. For example, category B schools recorded the highest ranking (3.3) for critical thinking with respect to perceived occurrences (Table 22). This ranking (3.3) is even lower than the least ranked perceived importance of 3.8. The perceived occurrence of teachers like the perceived importance of teachers is slightly higher than that of students. Teachers seem to involve in more activities that demand critical thinking skills.

Table 22: Respondents' perceived occurrences of the reduced factors of science process skills (N= 85 for teachers and N = 905 for students)

	Critical Thinking Skills	Mathematical/ Statistical Skills	Experimentation/ Problem Solving Skills	Argumentation Skills	N
Teacher	3.2	3.8	3.5	3.4	85
Students	3.1	3.9	3.5	3.5	905
Category A	3.2	3.5	4.0	3.4	353
Category B	3.3	3.5	3.8	3.4	288
Category C	3.2	3.4	3.4	3.2	264
Mean	3.2	3.6	3.6	3.4	

Author's Construct, 2019

For example, teachers plan and design experiments for demonstrations as well as for students' activities. There appears to be trend where perceived importance of critical thinking skill relates to perceived occurrence of critical thinking skill. For instance, both perceived importance and occurrence for teachers were higher than that of students. Also the perceived importance and occurrence of category B schools were also higher than that of category A schools. The only exception is category C schools with the highest ranking for perceived importance but the lowest ranking for perceived occurrence among the schools.

Critical thinking skills examine data and evidence critically to predict future occurrences or to draw inferable conclusions. This factor forms the basis for evaluation and interpretation of data since it carefully links data with theory. For example, most scientists operate in three main processes: Hypothesising, Experimentation and Evidence Evaluation (Klahr, Fay & Dunbar, 1993; Osborne, 2014). All these processes strive on data or evidence. Critical thinking skill examine data carefully to propose predictive statements (hypothesis) which is usually tested through carefully planned, designed and critically executed process (experimentation). The evidence gathered from experimentation is also evaluated through critical thinking skill which may lead to further hypothesis.

Mathematical/statistical skill seemed the most popular skill with mean perceived importance of 4.3 (Table 21). MoE (2010) acknowledged the need for Mathematical/statistical skill in science education. Mathematical skill is a major component of the pre-requisite skills required for successful sail through the SHS chemistry syllabus (MoE, 2010). This skill serves as both communicative and reasoning tool in science (Osborne, 2010). For example, the rate law in chemistry governing a specific reaction is expressed in mathematical symbols and formula. This rate law communicates the nature of the reaction and also predicts outcome based on the effect of altering available empirical data. The mathematical tool used in this instance, represent a general nature of the world and foretells specific effect based on future changes. The use of mathematical/statistical skill therefore provides logical deductive reasoning which is crucial in the process of evidence evaluation. The use of mathematical and inferential statistics is a common tool use to generate generalisation via evaluation of evidence. The ranking of teachers indicated 4.5 perceived importance which is greater than that of students (4.3). However, students' perceived occurrence (3.9) is slightly higher than that of teachers (3.8). Chemistry teachers generally, have more experience of mathematics (based on their level of education) than students which makes them understand better the nature of mathematics and its importance. Hence teachers' higher perceived importance. Students on the other hand, study mathematical courses (both core mathematics and elective mathematics) aside chemistry. Therefore, whereas the perceived occurrence of Mathematical/statistical skill for students at the SHS level is influenced by these mathematics programmes, that of teachers is restricted to activities concerning chemistry programme at the SHS level. This explains the higher perceived occurrence for students. The perceived occurrence for the schools decreased from category A schools (3.5) to category B schools (3.5) and then to category C (3.4), however the perceived importance for category B schools becomes an outlier for otherwise direct correlation between perceived importance and perceived occurrence for mathematical/ statistical skill.

The third reduced factor is Experimental/ problem solving skill. This skill helps students to gather empirical evidence as proof of knowledge. Recalling personal experience with students who resisted imposition of school science view of primary colours being red, blue and green against their view emerging from mixing pigments that primary colours consist of red, blue and yellow. These students insisted for a proof in order to discard/modify their ingrained view. The quest for scientific evidence is one of the three key competencies needed for scientific literacy (Bybee & McCrae, 2011). The experimental/ problem solving skill links the process of hypothesis to the process of experimentation. Hence the students were made to accept these two hypothesis: (1) that any combination of two filters made from primary colours will make the combined filter appear dark and (2) combined filters from filters made from secondary colours and any primary colour will appear like the combined primary colour if the filter of secondary colour has that primary colour, otherwise the combined filter appears dark. These evidence seeking students became convinced upon the evidence that yellow filters appear red when combined with red filters but appear green on combining with green filters. Though, the students' uncompromising stand appears irritating, it is in the spirit of science education to inculcate the value of scientific evidence into students. It is therefore refreshing that the mean ranking for the experimental/ problem solving skill was 4.2. This implies that majority of the respondents ranked the experimental/ problem solving skill at least, important. Students' perceived importance (4.3) and perceived occurrence (3.5) were higher than that of teachers (4.3, 3.5). The MoE (2010) expects teachers to employ experimentation as part of the teaching and learning of the content of the chemistry syllabus. Teachers are therefore under obligation to make the exercising of experimental/problem solving skill regular (MoE, 2010 expect two practical lessons per every six chemistry lessons) however, the evidence shows that all the analytical units ranked the skill below regular with mean ranking of 3.6. The reason(s) for low occurrence of practical activities is as a result of teachers' attitude towards practical activities and system constraints on them. However, it is common experience that students generally become excited whenever there are practical activities. Therefore, whereas the quest for practical activities may be spontaneous for students, teachers' quest may not necessarily be spontaneous. This analysis makes the higher perceived importance of students for experimental/ problem solving skill not surprising. The analysis in Tables 21 and 21 shows direct correlation for perceived importance and perceived occurrence for experimental/ problem solving skill across the units of analysis. For example, both perceived importance and perceived occurrence decreased from category A schools (4.3, 4.0) to category B schools (4.1, 3.8) and then to category C schools (4.0, 3.4). This skill is related to practical activity and hence the influence of facilities in the schools, which is crucial. The observed evidence of decreased trend in both perceived importance and occurrence across categories of schools A to C is expected since the preceding discussion asserted that the tendency of schools to have the required facilities decreased in that order.

The Argumentation skill examines data/evidence with respect to theory. This implies that the skill links the experimentation process to the evidence evaluation process. Though, this skill is crucial to the scientific process, it does not seem popular in science education (Watson, Swain & McRobbie, 2004). The analysis in Tables 21 and 22 shows the mean perceived importance and occurrence for Argumentative skill were 4.0 and 3.4 respectively. These are lower than that of Mathematical/ statistical skill (4.3;

3.6) and experimental/ problem solving skill (4.2; 3.6). However, teachers' perceived importance (4.2) was higher than that of students' (4.0) with students rather having higher perceived occurrence (3.5) than that of teachers (3.4). The higher perceived occurrence of students for Argumentation skill is surprising, considering the evidence that showed that 92.7% of teachers against 41.3% of students (Tables 14 & 15) indicated regular occurrence of talking, discussing and debating scientific issues. Argumentation skill involves communicating science through talking, debating or writing by relating scientific data against theory with the aim of passing the acid test of peer review and criticism. The fact that teachers' perceived occurrence of Argumentation skill is lower in view of majority of them (over 90%) claiming regular engagement of talking, discussing and debating scientific issues is an indication that majority of the teachers' talks and debates are rehearsal of the agreed explanations in the syllabus with little effort to engage in novel situations where these explanations are applied. Further evidence for the preceding assertion is shown in the low occurrence of problem solving activity through projects, case studies and field trips. Unlike material samples in the school science laboratories which are usually tested with nearly perfections, samples obtained from real authentic problem solving activity are usually messy and imperfect. The Argumentation skill is applied to minimise the noise and errors associated with the sample and sample collection process (Osborne, 2014). This implies that argumentation skill involves meta-knowledge of evidence adduced from experimentation or data collection to give account of the confidence level of the data collection process (Osborne, 2014).

The argumentative skill evaluates evidence through three forms of reasoning involving adductive argument, hypothetical-deductive and inductive generalisation (Osborne, 2014). When new idea is discovered in a specific domain, the scientist is faced with the problem of presenting or communicating the idea in a more concise or universal form to make the idea plausible to the scientific community. This problem is solved by relating the discovered idea to available theories and innovative mappings and representations (Klahr, Fay & Dunbar, 1993). This is the hypothesising space and requires critical thinking and mathematical/statistical skills. Beyond, the generation of the hypothesis, the hypothesis is exposed to plausibility test. The plausible hypothesis undergoes further evaluation via experimentation. The skills of experimentation as well as critical evaluation are employed to either confirm or falsify the claim of the hypothesis. The evidence from experimentation in terms of its predictability is compared to the predictability of the hypothesis in the evidence evaluation space. The evaluation and critique of evidence involve argumentation and projection of ideas. This may lead to generation of new hypothesis, scientific theory, model or even scientific

Students' Science Process Skills Developed at the End of Senior High School.

Research Question 4 sought to find out what science process skills SHS 3 students have developed at the tail end of their school programme to enable them write the WAEC examination in practical chemistry.

The SDSPS instrument was used to examine the extent of development of science process skills among SHS 3 students using 36 test items. The 36 items examines 9 variants in science process skills. These are observing, measuring, classifying, inferring/predicting, communicating, data interpreting, controlling variables, hypothesising and experimenting. The findings involving the proportion of students who had the various basic science process skills correct are analysed in Table 23.

Table 23: Percentage of respondents scoring correctly the basic science process skills in the test items correctly

Number of Test Item	Basic Science Skills	N	%
1	Observing	675	74.7
2	Observing	760	84.1
3	Observing	422	46.7
4	Observing	461	51.0
5	Measuring	363	40.2
6	Measuring	228	25.2
7	Measuring	563	62.3
8	Measuring	841	93.0
9	Classifying	227	25.1
10	Classifying	486	53.8
11	Classifying	395	43.7
12	Classifying	121	13.4
13	Predicting/Inferring	608	67.3
14	Predicting/Inferring	208	23.0
15	Predicting/Inferring	367	40.6
16	Predicting/Inferring	386	42.7
17	Communicating	589	65.2
18	Communicating	568	62.8
19	Communicating	598	66.2
20	Communicating	388	42.9
	SDSPS	**463**	**51.2**

Author’s Construct, 2019

Table 23 shows that the test items 1- 4 test the skill of Observing. Whereas 84.1% of the respondents had the test items 2 correct (highest proportion to score observing correctly), the test item 3 attracted the least percentage of respondents (46.7%) to get an item testing the skill of observing correctly.

The test item 2 expected respondents to identify scientific phenomena which can be observed by the sense of sight. The options to select from were (1) temperature of air (2) precipitation of salt (3) the sweetness of a new chemical and (4) the smell of perfume. Even if the respondents do not remember the concept of precipitation where solids are produced from liquids, majority may have remembered that the nose and tongue are used to smell and taste sweetness respectively. Also temperature is commonly felt or measured by thermometers. The ability to remember what the three phenomena stand for helps to eliminate the wrong options. However, the test item 3 expects respondents to estimate the distances between the white cloud of ammonium chloride (formed from the contact of ammonia and hydrogen chloride) and the initial positions of the particles of ammonia and hydrogen chloride. This involves knowledge of the reaction involving the two gaseous particles and inferences that the white cloud appeared as result of the reaction between the two particles. The item also demands respondents' ability to estimate distances which bothers on measuring skills. The context in which the skill of observing is being assessed in the test item 3 is therefore more complex. The difficulty in the item 3 therefore reflects the differences in the proportions of students being able to correctly respond to the two items testing the same skill of observing.

The test items 5 – 8 test the skill of measuring. The most correctly answered item testing measuring skill is the item 8 (Table 23). The test item 8 seems to be the easiest item for the respondents with 93% of the respondents accessing the item correctly. The test item 8 tests respondent's knowledge of the instrument the nurse uses to measure temperature. Aside, school science knowledge that thermometers are instruments used to measure temperature, the experience of the use of thermometers to check the temperatures of patients is very common to most of the respondents. It is therefore not surprising that this item recorded most correctly answered test item among the 36 test items in the instrument. The test item 6 however is the least correctly answered test item among those assessing the skill of measuring. The 25.2% of the respondents correctly accessing the test items 6 implies that nearly 75% of the SHS 3 students cannot estimate or do not know the correct unit of volume to estimate volume of acid required to react with zinc in a test tube. This shows that though most SHS 3 students may complete school knowing different units of volume, the majority of them are not able to perceive the quantity of liquid involved in those units.

The test items 9 – 12 in Table 23 examine the skill of classifying. Test items 12, testing the skill of classifying, is the least correctly responded item (13.4%) among the 36 items with the highest correctly accessed among the items testing classifying skills being the item 10 (53.8%). The item 10 contains four categories involving halogen, physical state, appearance, and reactions with alkali. Each category contains four items. Respondents were to realise that the category 'reactions with alkali' contains the same four items and therefore cannot be broken into further groups. Classification depends on similarities and differences in relationships. The findings show that 53.8% of SHS 3 students realise that in order to break properties into different groups, there must be differences as well as similarities. It also implies that about 46%

of SHS students may complete school without understanding this scientific fact. The test item 12 however, employs students to identify feature(s) in the atomic structures W and Y that put them in different groups as shown in Figure 21.

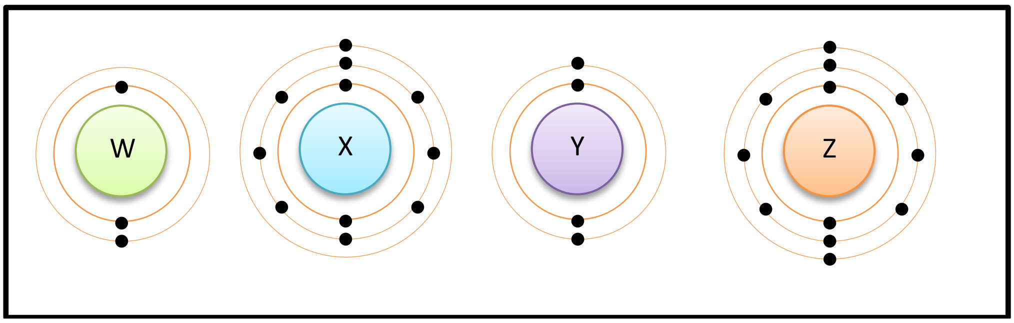


Figure 21: **Structures of four different atoms with electronic configuration**

In order to respond to the item 12 correctly, one must know and understand the features of the atomic structure. That is electrons, number of electrons, shells, inner shells and outer shells. Though these features are taught and rehearsed from the Junior high schools to the Senior high schools, 86.6% of the respondents failed to identify that the differences of number of electrons on the outer shell (one electron on the outer shell of W and two electrons on the outer shell of Y) put W and Y into different groups. It is quite surprising only 13.4% respondents could access this item correctly. It is difficult to argue from the content point of view since the content necessary to classify these structures is not outside what the respondents are expected to know. Perhaps, SHS students are not carefully instructed on what to look for as similar and difference in chemistry in order to classify. Personal experiences show that (1) most SHS students offer biology alongside chemistry, (2) SHS biology students engage a lot in classification however, the evidence adduced in this report shows that the WASSCE chemistry papers 2 and 3 and the specific objectives in the Chemistry syllabus (2010) hardly assess or develop the skill of classifying. It appears that though students engage in the development of the skill of classifying in biology, they are unable to transfer the skill of classifying into chemistry to compensate the lack of attention given to the skill in chemistry.

The items 13 – 16 test the skills of inferring and predicting. The items 13 and 16 assess the skill of predicting and the items 14 and 15 examine the skill of inferring. The least and most correctly accessed items among the items testing the skills of inferring and predicting are items 14 and 13 representing 23% and 67.3% respectively. The item 13 expects students to predict what happens when a liquid labelled highly inflammable is exposed to a naked flame. Though 67.3% of the respondents correctly predicted that the liquid will catch fire, majority of the 32.7% who responded unfavourably selected the option, ‘there was exothermic reaction’. It appears that this group of students though had some level of understanding in the term ‘inflammable’, the term ‘exothermic reaction’ may have misled them. The phenomena of fire like all instances of exothermic reaction though produce heat, not all exothermic reactions produce enough heat to set fuels ablaze. The two processes therefore are neither the same nor interchangeable. The item 14 on the other hand, expects students to infer the content of an unknown clear solution which gives out white precipitate upon adding barium chloride and hydrochloric acid by examining the data in Table 24.

Table 24: Solubility of barium and silver sulphates and chlorides

Reagent	$SO_4^{2-}{}_{(aq)}$	$Cl^{-}{}_{(aq)}$
$Ba^{2+}{}_{(aq)}$	Insoluble white solid	Soluble
$Ag^{+}{}_{(aq)}$	Soluble	Insoluble white solid

Author's Construct, 2019

The ability to respond correctly resides in connecting evidence to theory. The theoretical bases for the correct response are provided in the Table 29 with evidence expressed explicitly in the narratives of the item 14. The options that conclude that the sample contains barium and sulphate ions or silver and chloride ions could not be the correct inferences since both barium sulphate and silver chloride are insoluble which do not support the state of the sample as clear solution. The option that the sample contains either silver or chloride is also faulted because though the presence of silver precipitate white silver chloride, the presence of chloride will not initiate any visible reaction. The correct option is therefore the conclusion that the sample contains either sulphate or silver ions. The evidence in Table 20 shows that only 23% were able to make right deduction to access the item 14 correctly. The item 14 is the second least correctly accessed item among the 20 basic science process skill items in the SDSPS instrument.

The last items assessing the basic science process skills are the items 17 – 20 assessing the skill of communicating. The findings in Table 20 also shows that though 66.2% of the student respondents are aware that tables and graphs are appropriate communicative tools used to report experimental result involving monitoring the rate of reaction between hydrochloric acid and sulphur (response to item 19), 57.1% of them are not aware of the purpose of using tables and graphs (response to item 20). Whereas tables are usually used to provide details of data, graphs usually present trends or relationships among variables. The average proportion of the respondents getting the test items used to assess communicating skills was less than those getting the items testing observing skills correctly. The evidence for this assertion is found in Table 25 which provides means, standard deviations and percentages of the basic science process skills in descending order.

Table 25: Means, standard deviations and percentages of the basic science process skills in descending order.

S/N	Basic Science Process Skills	Max	Mean	SD	%
1	Observing	4	2.56	0.24	64.1
2	Communicating	4	2.36	0.32	59.3
3	Measuring	4	2.2	0.23	55.2
4	Prediction/Inferring	4	1.74	0.35	43.4
5	Classifying	4	1.36	0.24	34.0
	SDSPS index	**20**	**10.2**	**1.38**	**51.1**

Author’s Construct, 2019

The analysis in Table 25 orders the basic skills in hierarchical form with increasing difficulty to access by students as Observing, Communicating, Measuring, Inferring/Predicting and Classifying. Communicating skill being placed between Observing and Measuring skills is explained by the fact that while communication expresses observation either in verbal terms, in writing, in the use of graphs, tables and measurements add a well-defined inferent to communicate observations. The question that arises from the observed trend is, ‘should Inferring/Predicting precedes Classifying as the analysis reveals or should follow Classifying? Both variants depend on accurate observations. Whereas Classification depends on observable similarities, differences, and interrelationships to impose order, Inference/Prediction uses theory to explain, interpret or forecast future events following present observations. Since, observation is also said to be ‘theory laden’ it appears that the complexity and/or difficulties will be domain based. The evidence that science process skills depend on the content and context (domain) in which the skills are applied are shown in the preceding discussion. For example, the item 12 testing the basic skill of classifying was the most difficult item for the respondents. Also the item 8 testing measuring skill was the easiest items though the average correct score for the items assessing measuring skills (55.2%) was lower than those for communicating (59.3%) and observing skills (64.1%). However, the extent of development of the variants in basic science process skills among SHS 3 students as shown in Table 25 are observing (64.1), communicating (59.3%), measuring (55.2%), inferring/predicting (43.4%) and classifying (34%) in decreasing order. The general students’ development of science process skill (SDSPS) index for basic science process skill is however, 51.1%. The analysis of the integrated science process skills is contained in the Table 26 showing the percentage of respondents accessing the items testing the integrated science process skill correctly. Table 26 shows that the test items 21 – 24 assess controlling variables. Controlling variables involve the process of identifying variables, keeping some of the variables constant while varying others through manipulation of materials and equipment (Ongowo & Indoshi, 2013). Usually the process of varying variables is achieved through manipulation. The process of identifying and varying variables therefore represents the cognitive aspect of the physical manipulation of materials and equipment. Thus whereas Ongowo and Indoshi

(2013) used controlling variables in their report, Akinbobola and Afolabi (2010) used manipulating.

Table 26: Percentage of respondents scoring correctly the integrated science process skills in the test items correctly

Test Items	Integrated Science Skills	N	%
21	Controlling Variable	344	38.1
22	Controlling Variable	189	20.9
23	Controlling Variable	399	44.1
24	Controlling Variable	392	43.4
25	Data Interpreting	486	53.8
26	Data Interpreting	681	75.3
27	Data Interpreting	681	75.3
28	Data Interpreting	646	71.5
29	Hypothesising	368	40.7
30	Hypothesising	434	48.0
31	Hypothesising	162	17.9
32	Hypothesising	308	34.1
33	Experimenting	530	58.6
34	Experimenting	353	39.0
35	Experimenting	214	23.7
36	Experimenting	254	28.1
	SDSPS	**403**	**44.5**

Author’s Construct, 2019

This implies that controlling variables and manipulating are used interchangeably to represent the same science process skill. The most difficult item among the items testing controlling variables was item 22 with the item

23 being the easiest in that category. The item 23 sought to find out how students control the concentration and temperature of the decomposition of hydrogen peroxide using manganese oxide to monitor the effect of surface area on the rate. The evidence shows that 55.9% of the SHS 3 students failed to realised that all the other variables should be kept constant with variation of only the size of manganese oxide. The most surprising finding in this category is the proportion of the respondents that failed to get item 22 correct. Titration is a common investigational method used in chemistry. During this method, students usually select initial burette readings arbitrarily yet the actual titre volume is not affected. The titre is always derived from the difference between the initial burette reading and the final reading. However, only 20.9% of the students released that the initial reading of the burette is not among the factors that influence the value of the titre. The skill of identifying and controlling variables is an important aspect of the process of solving problems. When variables are identified and varied, they produce different effects and thus help to identify the best alternative to solve problems or increase the efficiency of particular process. However, manipulating of materials and equipment in science do not happen in pure trial and error manner but rather the scientists usually have certain skill that enables prediction of the outcome of manipulations within experimental space with certain level of confidence. MoE (2010) encourages teachers to assist students to not only develop the skill of hypothesising but also to equip them with the ability to criticize each hypothesis generated before selecting the best one. This implies that each hypothesis must be tested in order to criticize and to select the best. Thus, the three skills of controlling variables, hypothesising and experimenting usually

occur together in order to solve problems or to create innovations. It is therefore not surprising that the average SDSPS index of the three skills for the respondents were very close (Table 27).

Table 27: Means, standard deviations and percentages of the integrated science process skills in descending order

S/N	Integrated Skills	Max	Mean	SD	%
1	Data Interpretation	4	2.76	0.333	69.0
2	Experimentation	4	1.48	0.257	37.4
3	Controlling variables	4	1.48	0.248	36.6
4	Hypothesis	4	1.44	0.327	35.6
	SDSPS index	**16**	**7.16**	**1.165**	**44.7**

Author's Construct, 2019

The analysis in Table 27 indicates that percentage score of the respondents for experimenting, controlling variables and hypothesising are 37.4%, 36.6% and 35.6 respectively. The SDSPS index for the three integrated science process skills therefore becomes 36.5%. The skill of interpreting however is needed to evaluate and discuss the data collected by applying the preceding skills. Table 27 indicates that the skill of data interpreting is the most mastered skill. The evidences in the analysis of WASSCE Chemistry Papers 2 & 3 and the specific objectives of the chemistry syllabus all indicated that the skill of interpreting is the most prominent integrated science process skill. The high score of the respondents in the items assessing the skill of data interpreting among the integrated science process skills is therefore not surprising. It is however, surprising that the proportion of students that accessed the items in data interpreting were higher than those in the basic science process skills. Nevertheless, it is important to realise that chemistry students are offered two forms of mathematics programmes. That is core mathematics and elective mathematics. The two programmes expose students to different aspect of data manipulations and interpretations. These experiences explained the high mastering level of the skill of data interpreting among SHS 3 chemistry students. The SDSPS index for interpreting skill is 69.0 (Table 27). This value is higher than the highest variant (64.1%) in the basic science process skills. The general SDSPS index for integrated science process skill is however 44.7% which is lower than SDSPS index for basic science process skills (51.1%). Table 28 shows the proportion of students scoring the various grading levels in accordance with WAEC grading system.

Table 28: Proportion of students scoring at various grading levels of SDSPS (N= 905)

Proportion of students	Grade Range	Grading
22 (2.4)	75 – 100	A1
29 (3.2)	70 – 74	B2
120 (12.8)	65 – 69	B3
224 (24.8)	60 – 64	C4
323 (35.7)	55 – 59	C5
436 (48.2)	50 – 54	C6
489 (54.1)	45 – 49	D7
639 (70.7)	40 – 44	E8
904 (100)	0 – 39	F9

Author’s Construct, 2019

From Table 28, 48.2% of students scored A – C grades with 70.7% scoring A – E grades which represent pass grades.

Table 29 contains the prediction for the paper 2 and paper 3 of the WAEC examinations (see formulae in Appendix M).

Table 29: Prediction for WASSCE Papers 2 and 3 (N=905)

Paper	% Basic Skills	% Integrated Skills	Expected % (A1 – C6)	Expected % (A1 – E8)
Paper 2	87.90	12.10	50.3	73.8
Paper 3	81.38	18.62	49.8	73.0
Paper 3 (Q1)	81.65	18.35	49.9	73.2
Paper 3 (Q2)	79.00	21.00	49.7	72.9
Paper 3 (Q3)	89.58	10.42	50.4	73.9

Author's Construct, 2019

The analysis based on students' SDSPS index indicates that about half of SHS 3 students are not prepared adequately to make A1 – C6 grades in the WASSCE Chemistry examination. Since most tertiary institutions qualification for science programmes requires minimum of C6, it implies that about 50% of chemistry students are unable to pursue chemistry related programmes at the tertiary level. About one third chemistry students however, may not have chemistry appearing in their certificate since one need to pass the subject in order to have it indicated in the certificate.

Factors Influencing Development of Science Process Skills

Research Question 5 sought to found out factors that influence the development of science process skills.

The study observed six factors that influence the development of science process skills. These factors are the WAEC assessment, the specific objectives of the syllabus, literacy activity, laboratory activity and problem solving activity. The report has shown that the emphasised prominence of the WAEC examinations and the specific objectives of the chemistry syllabus with respect to their content of science process skills are basic science process skills (85.05% and 68.15% respectively). The corresponding analysis of the test scores in the SDSPS instrument showed that the student respondents scored higher SDSPS index for the basic science process skills (51.1%) than that of the integrated science process skills (44.7%). Also both the WAEC examinations and the specific objectives emphasised prominence for interpreting skill compared to the other integrated science process skill (6.28% for WASSCE Papers, and 22.9% for the specific objectives), the SDSPS index (69%) for interpreting skill was the highest among the integrated science process skills. The skill of classifying was among the least prominent skill in both WAEC (0.03%) and the syllabus (1.6%) and also recorded the least SDSPS index (34%). The analysis shows that both WASSCE Chemistry Papers and the specific objectives of the chemistry syllabus influenced the development of science process skills among the SHS students. The correlation test conducted for the WAEC papers and the specific objectives indicated $\chi = 0.820$. The high correlation value confirms the fact that WAEC depends on the specific objectives of the chemistry syllabus to assess students though the evidence in this report shows that their emphasis particularly for the integrated science process skills are different.

The analysis in Table 30 shows relationship between the mean frequency of occurrence of the various activities in the schools and the mean achievement test. The ranking of teaching and learning activities in the various schools indicated that literacy activities like reading, talking and discussing scientific issues occurred in descending order from category A schools to category C schools via category B schools (Table 30).

Table 30: Mean ranking of activities in the various schools

	R & T	% R & T	W & S	% W & S	L A	%LA	MS	% MS
Category A	3.3	66.0	2.3	46.0	3.0	60.0	20.0	55.6
Category B	3.2	64.0	2.8	56.0	3.1	62.0	19.9	55.3
Category C	3.0	60.0	3.6	72.0	2.7	54.0	17.5	48.6

Author’s Construct, 2019

R&T =Reading and Talking; W&S=Writing and symbolism; LA=Laboratory Activity; MS= Mean Score

The achievement test score correlated directly with reading & talking activities (Figure 21). However, the literacy activities of writing and the use of symbols correlated inversely with the achievement test as shown in Figure 22. When students engage in reading of scientific concepts, they became aware of science process skills and how to apply them. During discussions and debates students enrich their scientific knowledge and sharpen their evaluative skills. Higher order skills like inferring, predicting and integrated science process skills seem to develop more via reading and discussion as evidence in this study. The study shows that category A schools which engage more in these activities significantly achieve more of inferring, predicting and integrated science process skills. However, writing of laboratory report for example usually follow specific pattern or format which students usually enters data and information. Following prescribed pattern usually do not involve reflection, creativity and evaluations. Hence schools that engage more in such activities do not develop science process skills as compare to those engaging in reading, talking and debating scientific issues. This evidence concurred Chi (2009) to show that those who spent time reading around the concepts used in doing practical activities and discussed their experimental data benefited more in developing science process skills than those who merely followed procedures and formula to write and report on their empirical data.

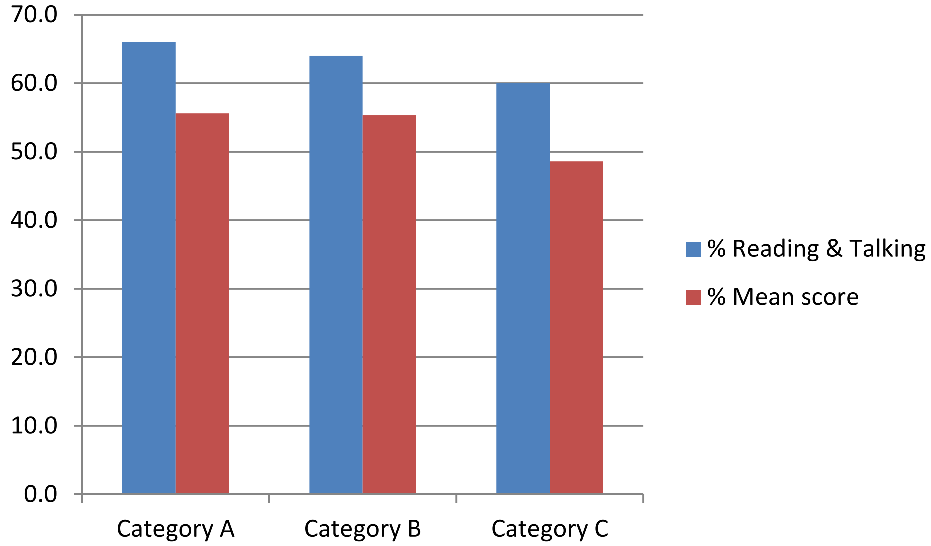


Figure 22: **Comparison of the ranking of Reading & Talking activities among the categories of schools (Author's construct, 2019.**

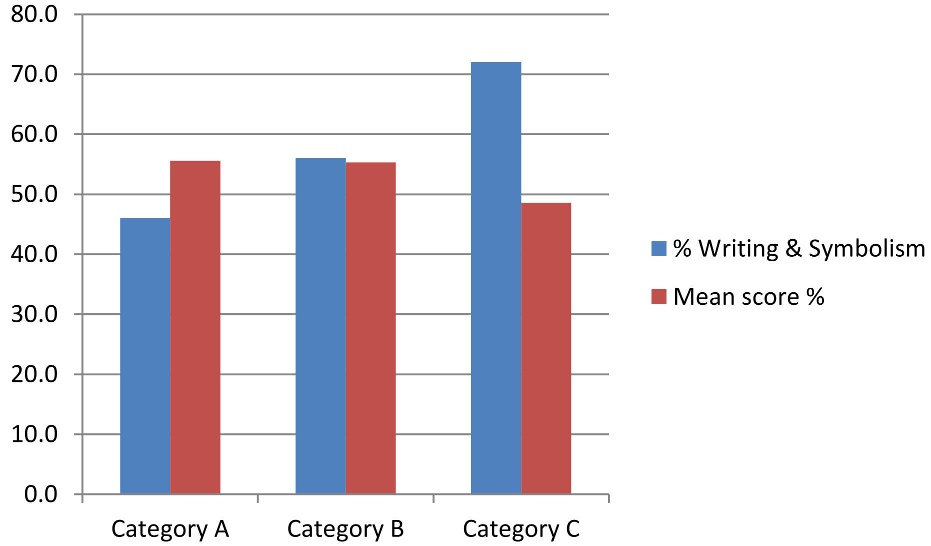


Figure 23: **Comparison of the ranking of the occurrence of Writing & Symbolism activities among the type of schools.**

Table 30 also indicated that both Category A and B schools had higher mean ranking for laboratory activities and also achieved higher scores for the achievement test than category C schools. However, literacy activity like reading, talking and debating scientific issues proved crucial factor and explains why category A schools outperformed category B schools though category B school had higher mean ranking for laboratory activity (Table 30). Evidence adduced in the study under the research hypothesis showed that category B schools were superior with respect to basic skills like observing and measuring which indicates the influence of higher engagement of laboratory activity. However, the power of reading, talking and debating empirical data gave category A schools advantage over category B schools with respect to skills like inferring, predicting and integrated science process skills. Gott and Murphy's (1987) study observed that students' failure in investigation is lack of knowledge and understanding of scientific procedure or strategies of scientific enquiry which seem to support the crucial effect of the literacy activity of reading, talking and debating scientific issues on the development of science process skills. Reading, talking and debating aspect of literacy activity seem to make students aware of the skills and sharpens their evaluative skills and their ability to link up concepts. Evidence in literature also suggested that problem solving activities like field trips, case studies and projects (Colley, 2006; Schwartz, 2014) are effective in developing science process skills thus the chemistry syllabus recommended their use at the SHS level. However, the effective use of literacy activity by category A schools seem to overshadow the adverse effect of problem solving activity on category A schools despite their relatively low involvement in such authentic activities. Table 31 shows that category A schools had the least mean ranking for all the problem solving activities (i.e., field trip, projects and case studies).

Table 31: Mean ranking of the problem solving activities of Field trips, Projects and Case studies among the type of schools.

	Field Trip	Project	Case	Total
Category A (mean)	1.7	2.63	2.24	6.57
Category B (mean)	2.56	3.56	2.59	8.71
Category C (mean)	1.86	2.85	2.35	7.06

Author's Construct, 2019

The preceding analysis showed that though, the three activities of literacy, laboratory and problem solving are crucial to develop science process skills, more benefits are achieved through effective engagement and reflection through talking, debating and reading.

Differences among School-type Students Attend and their achievement in Science Process Skills:

Hypothesis one explores significant differences if any between category of school attended by students and their science process skills.

The hypothesis was answered by analysing the scores obtained from the SDSPS instrument one-way ANOVA with the category of schools as unit of analysis. Table 32 shows the descriptive statistics of the scores obtained by the category of schools. The result shows the mean score in descending order of category A schools to category B schools and then category C schools. The observed trend is similar to the general assertion that category A schools are more resourceful than category B schools which are also more resourceful than category C schools.

Table 32: Descriptive statistics of the scores of science process skills among the category of schools

	N	Mean	SD	SE	95% CI		Min.	Max.
					Low. Bound	Up. Bound		
CAT A	352	20.0	5.1	.271	19.5	20.5	6.0	32.0
CAT B	288	19.9	4.5	.268	19.4	20.4	5.0	32.0
CAT C	264	17.5	4.4	.270	17.0	18.0	8.0	28.0
Total	**904**	**19.2**	**4.8**	**.162**	**18.9**	**19.6**	**5.0**	**32.0**

Author's Construct, 2019

CATA = category A schools; CATB = category B schools; CATC = category C schools

However, though the means are not the same, one can only conclude that indeed category A schools performed better when the means are tested for statistical significance. The analysis in Table 33 shows the ANOVA test for the mean scores.

Table 33: ANOVA for mean scores on science process skills among the category of schools

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1145.500	2	572.750	25.706	.001*
Within Groups	20075.313	901	22.281		
Total	**21220.813**	**903**			

Author's Construct, 2019

***significant, $p \leq 0.05$**

Table 33 indicates that there is significant difference among the mean scores of the type of schools at [F (2, 901) = 25.71, *p* = 0.001]. The details of how the difference occurred are shown by the Tukey Post Hoc analysis in Table 34

Table 34: Post Hoc analysis of the mean scores on science process skills among the category of schools

Dependent Variable: SPS

	(I) GP	**(J) GP**	**Mean Difference (I-J)**	**SE**	**Sig.**	**95% CI**	
						Lower Bound	**Upper Bound**
Tukey HSD	CAT A	CAT B	.125	.375	.940	-.756	1.01
		CAT C	2.53	.384	.001*	1.63	3.43
	CAT B	CAT A	-.125	.375	.940	-1.01	.756
		CAT C	2.40	.402	.001*	1.46	3.35
	CAT C	CAT A	-2.53	.384	.001*	-3.43	-1.63
		CAT B	-2.40	.402	.001*	-3.35	-1.46

Author’s Construct, 2019

***. The mean difference is significant at the 0.05 level.**

Post Hoc comparison using Tukey HSD test indicated that the mean score of category A schools (M = 20.0, SD = 5.1) and that of category B schools (M =19.5, SD= 4.5) were not significantly different. However, both the mean scores of categories A and B schools were found to be statistically different from the mean score of category C schools (M = 17.5, SD = 4.4) at p= 0.001. This implies that the category A and B schools outperformed the category C schools. The preceding analysis looks at the general outlook of the science process skills but the skills were examined by using 36 items to assess nine different variants of science process skills. Table 35 shows that the mean scores of both category A and B schools were higher than that of category C schools across all the dependent variables (observing, measuring, classifying, inferring/predicting and communicating). The category A schools outperformed the category B schools in the classifying, inferring/predicting and communicating skills while the category B school had the upper hand in the observing and measuring skills.

35: Descriptive statistics of the scores of the basic science process skills among the category of schools

				95% CI	
Dependent Variable	**GP**	**Mean**	**SE**	**Lower Bound**	**Upper Bound**
	CAT A	2.696	.050	2.598	2.794
Observing	CAT B	2.711	.055	2.603	2.820
	CAT C	2.220	.058	2.107	2.333
	CAT A	2.230	.047	2.138	2.322
Measuring	CAT B	2.491	.052	2.389	2.593
	CAT C	1.856	.054	1.750	1.962
	CAT A	1.423	.050	1.326	1.521
Classifying	CAT B	1.408	.055	1.300	1.516
	CAT C	1.212	.058	1.099	1.325
	CAT A	1.881	.053	1.776	1.985
Inferring/predicting	CAT B	1.757	.059	1.641	1.872
	CAT C	1.508	.061	1.387	1.628
	CAT A	2.795	.063	2.672	2.919
Communicating	CAT B	2.561	.069	2.425	2.697
	CAT C	1.591	.072	1.449	1.733

Author’s Construct, 2019

Table 36 shows the mean scores for integrated science process skills.

Table 36: Descriptive statistics of the scores of the integrated science process skills among the category of schools

			GP		
				95% Confidence Interval	
Dependent Variable	**GP**	**Mean**	**Std. Error**	**Lower Bound**	**Upper Bound**
Controlling Variables	CAT A	1.582	.052	1.480	1.685
	CAT B	1.545	.058	1.432	1.658
	CAT C	1.205	.060	1.086	1.323
	CAT A	3.094	.066	2.965	3.222
Data Interpreting	CAT B	2.642	.072	2.500	2.784
	CAT C	2.432	.076	2.283	2.580
	CAT A	1.625	.053	1.521	1.729
Hypothesis	CAT B	1.318	.059	1.202	1.433
	CAT C	1.205	.061	1.084	1.325
	CAT A	1.687	.054	1.582	1.793
Experimenting	CAT B	1.456	.059	1.339	1.573
	CAT C	1.258	.062	1.136	1.379

Author’s Construct, 2019

The mean scores of the integrated science process skills show that the category A schools outperformed both category B and C schools in all the four dependent variables. The category B schools also performed better in controlling variables, data interpreting, experimenting and hypothesising skills than category C schools. The result of multivariate analysis of variance performed on the mean scores for the nine dependent variables with school category as independent variables is shown in Table 37.

Table 37: Multivariate analysis on variants of science process skills and the category of schools

Effect	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Wilks' Lambda	.057	1638.2	9.0	893.0	.000	.943

Author’s Construct, 2019

Table 37 shows Wilks’ Lambda value of 0.057 at [F (9,893) = 1638.2, P < 0.001]. This implies that the mean scores of the category of schools for the nine variants of science process skills are not the same. The Tables 38 and 39 show which of the dependent variables are different statistically among the school categories for the scores of the basic science process and the integrated science process skills respectively. All the mean score differences observed between category A and B schools for the basic skills were found to be statistically insignificant except that of measuring and communicating.

Table 38: Post Hoc analysis of the mean scores on the basic science skills and the category of schools

			Mean			95% C I	
			Dif.	SE	Sig.	Lower	Upper
Dependent Variable	(I) GP	(J) GP	(I-J)			Bound	Bound
Observing	CATA	CATB	-.015	.074	.977	-.190	.159
	CATA	CATC	.473	.076	.001*	.297	.655
	CATB	CATC	.492	.079	.001*	.304	.680
Measuring	CATA	CATB	-.261	.070	.001*	-.425	-.097
	CATA	CATC	.374	.072	.001*	.206	.542
	CATB	CATC	.635	.075	.001*	.459	.811
Classifying	CATA	CATB	.015	.074	.977	-.159	.190
	CATA	CATC	.211	.076	.016*	.033	.390
	CATB	CATC	.196	.080	.038*	.001	.383
Inferring/Predicting	CATA	CATB	.124	.079	.262	-.006	.310
	CATA	CATC	.373	.082	.001*	.182	.563
	CATB	CATC	.249	.085	.010*	.049	.449
Communicating	CATA	CATB	.235	.094	.033*	.015	.454
	CATA	CATC	1.205	.096	.001*	.979	1.430
	CATB	CATC	.970	.100	.001*	.734	1.206

Author's Construct, 2019

While the category B schools (M=2.491, SD=0.47) outperformed the category A schools (M=2.230, SD= 0.52) significantly (p = 0.001), the category A schools (M=2.795, SD=0.063) performed better than category B schools (M=2.561, SD= 0.069) for communicating skill at significance of p = 0.024. The mean scores of both category A and B schools were found to be positive and significantly different from category C schools for all the basic science process skills.

It was found that category A (M=1.582, SD=0.52) and B (M=1.545, SD=0.58) schools were not different with respect to their mean scores in controlling variables but both of them were different from category C schools (M=1.205, SD=0.060) in the same variable. Table 39 also shows that the mean scores for category A schools for data interpreting, hypothesising and experimenting skills were positive and significantly different from category B and C schools. The differences between the mean scores for category B and C schools for data interpreting, hypothesising and experimenting skills were not found to be significant.

Table 39: Post Hoc analysis of the mean scores on the integrated science skills and the category of schools

			Mean			95% CI	
			Dif.	SE	Sig.	Lower	Upper
Variable	(I) GP	(J) GP	(I-J)			Bound	Bound
Controlling	CATA	CATB	0.037	0.078	0.88	-0.145	0.22
Variables	CATA	CATC	0.377	0.078	.001*	0.191	0.564
	CATB	CATC	0.34	083	.001*	0.145	0.535
Data	CATA	CATB	0.45	0.098	.001*	0.22	0.68
Interpreting	CATA	CATC	0.66	0.1	.001*	0.43	0.9
	CATB	CATC	0.21	0.105	0.11	-0.04	0.46
Hypothesising	CATA	CATB	0.307	0.08	.000*	0.121	0.493
	CATA	CATC	0.421	0.081	.000*	0.223	0.611
	CATB	CATC	0.113	0.081	0.378	-0.086	0.313
Experimenting	CATA	CATB	0.232	0.08	.011*	0.044	0.42
	CATA	CATC	0.43	0.082	.001*	0.237	0.623
	CATB	CATC	0.198	0.086	0.055	-0.004	0.4

Author’s Construct, 2019

The preceding analysis has shown that the mean scores obtained by the category of schools were not the same. The result of the analysis showed that the means of the three categories of schools were different in at least one of the variants. The Null Hypothesis that ‘there is no significant difference between type of school attended by students and their science process skills’ cannot be held rather the Alternative Hypothesis ‘there is significant difference between type of school attended by students and their science process skills’ is sustained.

Statistical Difference between Gender of Students and their Development of Science Process Skills

Null Hypothesis two (H_{O2})

There is no significant difference between gender of students and their science process skills.

The hypothesis is answered by analysing the male and female students' scores obtained from the SDSPS instrument using analysis of variance (ANOVA) and multivariate analysis of variance. Table 40 shows the descriptive statistics of the scores obtained by male and female students.

Table 40: Descriptive statistics of male and female students' scores of the basic science process skills

	N	Mean	SD	SE	95% CI Lower Bound	95% CI Upper Bound	Min.	Max.
Female	453	18.2	5.0	.237	17.7	18.6	6.0	29.0
Male	451	19.5	5.1	.241	19.0	20.0	5.0	33.0
Total	904	18.8	5.1	.170	18.5	18.5	5.0	33.0

Author's Construct, 2019

The analysis in Table 40 shows that the mean score of male students is higher than that of female students. The statistical significance of the mean difference is however found in ANOVA analysis contained in Table 41. The analysis in Table 41 shows that the mean score for male students (M=19.5, SD=5.1) was significantly different from that of female students (M=18.2, SD=5.0) at effect of [F (1, 902) =15.5, p< 0.001].

Table 41: ANOVA analysis on male and female students' scores in science process skills

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	399.5	1	399.5	15.5	.000
Within Groups	23283.4	902	25.8		
Total	**23682.9**	**903**			

Author's Construct, 2019

Tables 42 and 43 contain the descriptive statistics of the variants in basic and integrated science process skills respectively for male and female students. Table 42 indicates that apart from the skill of observing, the mean scores of all the variants in the basic science process skills are higher for the male students than that of the female students.

Table 42: Descriptive Statistics of the variants in the basic science process skills for male and female students

	Gp	Mean	Std. Deviation	N
Observing	Female	2.57	.990	453
	Male	2.55	.933	451
Measuring	Female	2.11	.890	453
	Male	2.30	.920	451
Classifying	Female	1.30	.940	453
	Male	1.41	.935	451
Inferring/Predicting	Female	1.72	1.01	453
	Male	1.73	1.01	451
Communicating	Female	2.28	1.28	453
	Male	2.37	1.28	451

Author's Construct, 2019

However, Table 43 shows that female students scored higher in all the variants in the integrated science process skills.

Table 43: Descriptive Statistics of the variants in the integrated science process skills for male and female students

	gp	Mean	Std. Deviation	N
Controlling Variable	Female	1.49	1.04	453
	Male	1.43	.944	451
Data Interpreting	Female	2.77	1.17	453
	Male	2.75	1.34	451
Hypothesising	Female	1.42	1.02	453
	Male	1.39	1.01	451
Experimenting	Female	1.51	1.06	453
	Male	1.47	.989	451

Author’s Construct, 2019

The MANOVA analysis in Table 44 shows that at least one of the mean differences is significant (Wilks’ Lambda value of 0.063 at F = 1483.7, p< 0.001).

Table 44: Multivariate analysis on male and female scores for the variants in science process skills

Effect	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Wilks' Lambda	.063	1483.7	9	894.0	.000	.937

Author’s Construct, 2019

The Post Hoc analyses in Table 45 shows that all the mean differences in the various variants are insignificant except that of measuring and communicating. The mean (M = 2.3, SD = 0.920) for males is found to be significantly superior to that of females (M = 2.11, SD = 0.890) at p = .002 for measuring. Similarly in communicating, the mean (M = 2.37, SD = 1.28) for males significantly outperformed that of females (M = 2.28, SD = 1.28) at p = .043.

Table 45: Post Hoc analysis on male and female scores for the variants in science process skills

Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Observing	.075	1	.075	.081	.776
Measuring	8.34	1	8.343	10.080	.002
Classifying	2.60	1	2.603	2.963	.086
Inferring/Predicting	.187	1	.187	.193	.661
Communicating	6.73	1	6.73	4.180	.043
Controlling Variables	.705	1	.705	.718	.397
Data Interpreting	.104	1	.104	.065	.798
Hypothesising	.218	1	.218	.212	.645
Experimenting	.451	1	.451	.430	.512

Author’s Construct, 2019

The preceding discussions show that the overall mean difference in science process skills for male and female students is statistically significant. Therefore the Null hypothesis that ‘there is no significant difference between gender of students and their science process skills’ is rejected.

In mixed school environments, boys are likely to disrupt class, intimidate girls and put girls down when girls attempt to express themselves.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This chapter summarises the study, key findings and draws conclusion and generalisations of the study. It also provides recommendations and suggestions for further studies.

Overview of the Study

The study investigated how students develop science process skills at the SHS level. To investigate the problem, the following five research questions and two hypotheses were formulated to guide the study.

Questions

(1) What science process skills have been assessed in the WAEC examinations in the past five years and where has been the emphasis?'

(2) What opportunities are given to students to help them develop science process skills in schools?

(3) What are SHS chemistry teachers' and students' perception of importance and occurrence of the development of science process skills?

(4) What science process skills have SHS 3 students developed at the tail end of their school programme to enable them write the WAEC examination in practical chemistry? and

(5) What factors influence the development of science process skills by SHS chemistry students?

Hypotheses

(1) There is no significant difference among category of schools attended by students in developing their science process skills was H_{O1}

(2) There is no significant difference between genders of students in developing their science process skills was H_{O2}.

Documentary analysis was used to explore how the chemistry syllabus and the external assessment body (WAEC) influence the development and assessment of the skills. To gain more holistic view of the study, two instruments were used. The first was a cross sectional survey questionnaire which found out the opportunities available to students to develop science process skills and teachers' and students' perceived importance and occurrence of science process skills. The second instrument was parametric achievement test which assessed the level of science process skills students had achieved by the end of their final year in senior high school. The hypotheses sought to find out whether school type and gender had influence on the development of science process skills.

Key Findings

1. It was found that WAEC examinations assessed both integrated and basic science process skills from 2012 to 2016. The assessment however, gave more prominence to basic science process skills (85.05%) than integrated science skills (14.95%). The basic science process skills identified were communicating (38.12%), recording (15.99%), calculating (8.67%), observing (8.52%), inferring (8.52%), measuring (2.24%), predicting (1.79%), drawing (0.9%) and classifying (0.3%) in decreasing order of emphasis. The integrated science process skills found in the WAEC examination over the five years period in decreasing order of emphasis were interpreting (6.28%),

manipulating (6.13%), investigating (1.79%) and experimenting (0.75). The integrated science process skills are essential skills in science and technology which are used for creative thinking to solve scientific problems hence their low emphasis in the WAEC examination does not help the students to develop these skills.

2. The opportunities given to SHS students to develop science process skills were mainly through laboratory activity, literacy activity, problem solving activity and through following the specific objectives in the WAEC chemistry syllabus. Literacy activity like reading, talking and debating scientific issues and data from experiments was found to be lacking particularly in category C schools.

3. The study found that both students and teachers perceived that science process skills and the 14 variants used for the study were important concepts to develop in chemistry education. However, they also perceived that the development of these concepts in the teaching and learning process at the SHS level was not a regular feature of the teaching and learning of chemistry. Even though both students and teachers regarded science process skills as essential skills required in chemistry education, the development of these skills were not a regular feature of the teaching and learning process.

4. The science process skills, which students had developed adequately to prepare them for their WASSCE examination, were observing, communicating, measuring and interpreting tables and graphs. Students had not well developed the skills of inferring, predicting, classifying and other integrated science process skills like hypothesising, controlling variables and experimenting.

5. Five factors were identified to influence the development of science process skills by SHS chemistry students. These were:

(i) the nature of the WAEC examinations,

(ii) the nature of the specific objectives in the chemistry syllabus,

(iii) Literacy activity,

(iv) Laboratory activity and

(v) Problem solving activity

6. The development of the skills were significantly different among the type of schools at significance effect of [F (2, 901) = 25.71, p = 0.001]. The mean scores of category A schools (M = 20.0, SD = 5.1) and that of the category B schools (M = 19.5, SD = 4.5) were found not to be statistically different. However, both category A and B schools were statistically different from category C schools (M = 17.5, SD = 4.4) in developing science process skills (at $p < 0.001$).

7. There was statistical difference between males (M=19.5, SD=5.1) and females (M=18.2, SD=5.0) at effect of [F (1, 902) =15.5, p< 0.001. However, whereas males and females in category B schools were found to be similar, female outperforms males significantly in category A schools with males significantly outclassing females in category C schools.

Conclusions

The study set out to answer five questions and two hypotheses. In answering the first question, it emerged that WAEC WASSCE chemistry paper 2 and 3 give more prominence to basic science process skills with little emphasis in assessing and developing integrated science process skills. These findings are similar to what is found in the literature involving assessment of biology and physics. The study therefore adds to the literature, the nature of chemistry assessment with respect to the development of science process skills. The study also complements what is known in the assessment of biology and physics and implies that though assessment in secondary science education helps students to be aware and understand nature by developing and accessing basic science process skills, it fails to engage students in reflective thinking and scientific problem solving skills by de-emphasising assessment and development of integrated science process skills. The study creates awareness of the differences in emphasis in the assessment of science process skills in the three pure sciences. For example, while biology emphasises prominence in assessing the skill like classifying, Chemistry and physics hardly assess the classifying skill whereas experimenting was more prominent in physics assessment than investigating, chemistry assessment, according to this study showed higher prominence in investigating skills than experimenting skills.

In the quest to answer the second question, the opportunities available to students to develop science process skills were classified as literacy activity, laboratory activity and problem solving activity. These classifications were synthesised from 5 practices of science and inquiry approaches known in the literature. The perception of students and teachers on the engagement of the three activities were low signifying the need to increase the effort to make these activities regular features of school practice if policy makers and the school systems agree with students and teachers in regarding the development of science process skills as important aspect of science education.

The answer to the third research question revealed that both teachers and students regard science process skills and the associated 14 variants as important in chemistry education but they also admitted that the skills were not regular features of the process of teaching and learning.

The effect of irregular development of science process skill was evidenced in the outcome of the achievement test which sought to answer research question four. The findings that students develop a few of the basic science process skills like communicating, observation and measuring with most of the integrated science process skills undeveloped at the tail end of their SHS experience confirms the prominence given to the assessment and development of basic science process skills in literature with dire implication for practice. The evidence in literature revealed that there is a ceiling set to the proportion of students that have the capacity to access integrated science process skills which require formal operation thinking. Hence, students' low performance in the integrated science skills was not as surprising as that of basic science process skills like inferring, predicting and classifying. The development of skills like inferring, predicting and the integrated science process skills are essential tools for self-reliance, understanding the world around us and solving problems through science and technology.

The benefit of science process skills makes the implication of the model for skills and processes required for scientific enquiry developed in the study crucial for science education.

The study also confirms literature evidence that development of science process skills by students from difference background has significance statistical differences. This report showed the confirmation by providing evidence to the effect that the three categories of schools examined were all significantly different from each other. It also provides evidence that gender differences exist between some of the specific skills. Gender stereotyping, intimidation and disruption from males may account for underperformance among females in mixed school environment. These findings emerged from the two hypotheses raised in the study.

The research design used to understand the problem has been successful. The document analysis approach adopted to use the specific objectives of the chemistry syllabus and the WAEC WASSCE papers as instruments provided the true account of how science process skills are developed and assessed at the SHS level since these instruments are the documents used to guide and assess teaching and learning. Understanding the development of science process skills from the perspective of teachers and students' perceived importance and occurrence also seemed appropriate. One may argue that direct observations or combination of observations and the approach used may be more appropriate design. However, it is worth noting that teaching and learning being human behaviour is quite fluid. What is observed in a specific period may or may not bear resemblance to the observation made in different periods though the entity understudy may be similar. Nevertheless, perception emanates from accumulation of different experiences and therefore has the potential to portray a picture that is closer to the real situation than pockets of observations. Furthermore the author has significant experience of teaching, mentoring and observing classroom practices so understanding this important classroom experience with the lenses of people's view seems suitable. The test items instrument has also proved to have discriminative and predictive effect making the study a success.

The study developed conceptual framework that advocates for science process skills to occupy the central theme of the chemistry syllabus. Other important contribution of the study is unifying inquiry, projects, case study, field trips and problem based instructions in a single model. This gives better understanding of these instructional approaches.

Recommendations

The following are recommended in the light of the research findings.

1. To avoid over-emphasis in communicating learnt concepts and ideas WAEC should take steps to decrease the level of test items that seek to solicit communicating learnt concepts and increase items that test science process skills like inferring, predicting and integrated science process skills. The skills of inferring and predicting help to study patterns leading up to the understanding of the world around us while integrated science process skills help to formulate scientific solutions for everyday life challenges.
2. The perception of teachers and students showed that there were low opportunities to engage in literacy, laboratory and problem solving activities therefore Ghana Education Service and old students associations must ensure adequate resources like laboratory and library facilities, and school buses to enhance laboratory, literate and problem solving activities in schools. Also WAEC must take steps to monitor and assign marks to necessary manipulations in the practical papers. This will compel candidates to follow and perform all the manipulating

procedures required of them in the practical paper. This action will not only ensure that the school systems prepare candidates adequately before the practical paper but also make candidates develop essential skills to help solve scientific and technological problems

3. The opportunities to develop science process skills were found not to commensurate the level of attachment of importance to the development of science process skills by teachers and students. Ghana Education Service and science educators should ensure that teachers include the development of the skills as part of lesson plan preparations. This will ensure that teachers think through activities and carefully support students to develop the skills.
4. The development of science process skills index among SHS students were found to be low therefore GES in collaboration with academic science educators should organise seminars, workshops and conferences for school administrators, teachers and students on the need for the development of science process skills and the benefits of the skills on the growth and development of the nation. These activities will increase the awareness of the science process skills and ensure all stakeholders do their best to ensure development of the skills.
5. The Curriculum Research and Development Division of GES should take steps to reduce proportion of the specific objectives focussed on developing skills of communicating scientific terms and concepts (using verbs like define, state, list etc.) and increase the proportion of specific objectives that focus on developing critical thinking skills, argumentation skills, experimental/problem solving skills and

mathematical/statistical skills. These skills reflect the essential tools used by scientists to solve scientific problems and therefore their development at the SHS level will equip and prepare students to embrace science and technological challenges.

6. The differences in the development of science process skills among the categories of schools suggests that the provision of facilities and the school systems played important role in developing science process skills. The Ministry of Education and GES should ensure uniform distribution of resources to avoid discrimination of opportunities to Ghanaian students in developing science process skills. The school administrators in low grade schools should make effort to encourage old school associations to support them.
7. Since females perform better in single sex school environments, single ‘prepping’ where female students are separated from male students to study in private should be encouraged in mixed school environments. Also female should be grouped separately from males during practical activities and group discussions. The school system must ensure all gender barriers are removed to ensure gender parity.

Suggestions for Further Studies

In the course of the study issues like how to effectively develop the skills and appropriate contexts and resource became apparent. The following research areas are therefore suggested for further studies.

1. Developmental research is needed to identify the most effective way to develop science process skills at the SHS level.

2. Investigation is needed to ascertain relevant science process skills needed and applied in chemistry based on industries and companies in Ghana.
3. Investigation is needed to confirm or otherwise whether gender difference in the development of communicating and measuring skills are significant.

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APPENDICES

APPENDIX A: CLASSIFICATION OF SPECIFIC OBJECTIVES IN SHS 1

Specific Objective	Code
1.1.1 Describe chemistry as a subject…	Communicating
1.1.2 Describe the various branches of chemistry	Communicating
1.1.3 Outline some careers in chemistry and their importance	Communicating
1.2.1 Describe the importance of scientific measurements to the study of chemistry.	Communicating
1.2.2 Measure some physical quantities using appropriate instruments.	Measuring
1.2.3 Identify the uses laboratory equipment.	Communicating
1.2.4 Differentiate between basic and derived units of measurement.	Inferring
1.2.5 Outline the scientific method.	Communicating
1.3.1 Read and follow rules and instructions in the laboratory.	Communicating
1.3.2 Explain what hazard symbols are and relate their importance to the handling and use of laboratory chemicals and equipment.	Interpreting
1.3.3 Handle some minor laboratory accidents and give first aid.	Manipulating;
1.3.4 Outline the need to have personal protective equipment in the chemistry laboratory.	Communicating
1.3.5 Explain why some chemicals should not be stored alphabetically.	Interpreting.
1.3.6 Quench small fire in the laboratory.	Manipulating;
2.1.1 Describe the characteristics and nature of matter.	Communicating
2.2.1 Explain Dalton’s atomic theory.	Interpreting
2.2.2 Describe the various experiments that were carried out to reveal the structure of the atom.	Communicating
2.2.3 Write detailed electron configurations (s, p, d) for atoms of the first thirty elements.	Communicating
2.2.4 Describe an isotope.	Communicating
2.2.5 Describe the operations of the mass spectrometer.	Communicating
2.3.1 Relate the position of an element in the periodic table to its atomic number and electron configuration.	Interpreting

2.3.2 Use the periodic table to identify metals, semimetals, non-metals and halogens.	Inferring
2.3.3 Describe the physical and chemical properties of some representative elements.	Communicating
2.3.4 Distinguish between the terms, group, and period	Interpreting
2.3.5 Explain the periodic law	Interpreting
2.3.6 Identify trends in atomic size, ionization energy, electron affinity, electronegativity and ionic size for elements on the periodic table.	Communicating
2.3.7 Describe the periodic gradation of elements in the third period.	Communicating
2.3.8 use the periodic table to determine the number of electrons available for bonding	Interpreting
3.1.1 Explain the meaning of a chemical bond.	Interpreting
3.1.2 Describe how ionic bond is formed between two chemical species.	Communicating
3.1.3 Draw Lewis dot structures for simple ionic compounds.	Drawing
3.1.4 Identify factors that promote the introduction of covalent character into ionic bond.	Communicating
3.1.5 Name some binary and ternary ionic compounds from their formulae and write formulae from their names.	Communicating
3.1.6 Describe the general properties of ionic compounds.	Communicating
3.1.7 Describe how covalent bond is formed.	Communicating
3.1.8 Draw Lewis dot structures for some covalent compounds.	Drawing
3.1.10 Describe how metallic bond is formed.	Communicating
3.1.11 state and describe the properties of metals.	Communicating
3.2.1 Describe the different types of intermolecular forces found in covalent compounds.	Communicating
3.2.2 Explain how intermolecular forces arise from the structural features of molecules.	Interpreting
3.2.3 Describe how intermolecular forces affect the solubility melting point and boiling points of substances.	Communicating
3.1.9 Describe the properties of covalent compounds.	Communicating
3.2.4 Describe the formation of hydrogen bond.	Communicating
3.2.5 Describe the existence of van der Waals forces between covalent molecules.	Communicating

3.3.1 Explain the term, hybridization.	Interpreting
3.3.2 Describe how sp3, sp2 and sp hybrid orbitals are formed.	Communicating
3.3.3 Describe how sigma and pi-bonds are formed.	Communicating
3.3.4 Illustrate the shapes of given molecular compounds.	Inferring
4.1.1 describe the Carbon12 scale of measurement of mass	Communicating
4.1.2 Explain relative atomic and molecular mass.	Interpreting
4.1.3 Explain the mole as a unit of measurement of amount of substance	Interpreting
4.1.4 Identify molar quantities of substances.	Communicating
4.1.5 Calculate amount of substance, number of entities and molar quantities from a given data.	Calculating
4.2.1 explain solute, solvent and solution and give examples	Interpreting
4.2.2 Prepares solutions of given concentration from solid solutes.	Manipulating
4.2.3 Prepare solutions of given concentration from liquid solutes by diluting a concentrated solution.	Manipulating
4.2.4 Explain the terms primary standard, secondary standard and standardized solution.	Interpreting
4.3.1 Write correct formula for named chemical compounds.	Communicating
4.3.2 Write the name of a given compound correctly.	Communicating
4.3.3 Write and balance chemical equations	Communicating
4.3.4 Explain the laws of chemical combination.	Interpreting
4.3.5 Demonstrate the principle of conservation of matter through experiment.	Experimenting
4.3.6 Identify and write mole ratios for chemical species in balanced chemical equations.	Communicating
4.3.7 Determine limiting and excess reagents in a chemical reaction	Calculating
4.3.8 Determine the formula of compounds from experimental and given data.	Interpreting
4.3.9 Determine the formula of magnesium oxide through experiment.	Experimenting
4.4.1 Explain some terms associated with the nucleus of the atom.	Interpreting
4.4.2 Identify stable and unstable nuclide.	Communicating
4.4.3 Classify nuclear reactions as spontaneous or	Classifying

stimulated/induced nuclear reactions.	
4.4.4 identify the main types of emissions that occur in radioactivity	Communication
5.1.1 Describe the characteristics and nature of solids.	Communicating
5.1.2 Relate the properties of solids to the type of interatomic or intermolecular bonding in the solids.	Interpreting
5.1.3 Outline some uses of diamond and graphite.	Inferring
5.1.4 Determine the melting point of some covalent solids.	Manipulating
5.1.5 Describe the characteristics and nature of liquids.	Communicating
5.1.6 Distinguish between vapour and gas.	Inferring
5.1.7 Make a liquid boil at a temperature below its boiling point.	Experimenting
5.2.1 Describe the characteristics and nature of gases.	Communicating
5.2.2 Describe the laboratory preparation of hydrogen, ammonia and carbon dioxide.	Communicating
5.2.3 Use the gas laws to explain the behaviour of gases under different conditions.	Interpreting
5.3.1 Explain the kinetic theory of matter.	Interpreting
5.3.2 Relate the speed at which different gas particles move to the masses of the particles.	Interpreting
5.3.3 demonstrate diffusion in liquid	Experimenting

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APPENDIX B: CLASSIFICATION OF SPECIFIC OBJECTIVES IN SHS 2

Specific Objective	Code
1.1.5 Describe the enthalpy change associated with burning of food and fuels.	Communicating
1.2.1 Define and use the terms standard state and standard enthalpy change of formation fH combustion cH and neutralization( ) ° nHΔ .	Communicating
1.2.2 Determine the enthalpy change associated with chemical reactions using experimental data.	Calculating
1.2.3 Determine the heat of combustion of a given fuel.	Experimenting
1.2.4 Explain Hess‟s law of constant heat summation and its application in the development of the Born- Haber cycle.	Interpreting
1.2.5 Determine the enthalpy of neutralization for a given acid-base reaction.	Experimenting
1.2.6 Explain bond energy and bond dissociation energy.	Interpreting
2.1.1 Describe the patterns in physical and chemical properties of the period 3 elements.	Communicating
2.1.2 Describe the pattern in physical and chemical properties of compounds of period 3	Communicating
2.1.3 Account for the differences in thermal stability of the trioxocarbonate(IV) and trioxonitrate(V) of some metals.	Interpreting
2.1.4 Demonstrate the thermal stabilities of some trioxocarbonate(iv) in the laboratory	Experimenting
2.1.5 Describe the uses of Silicon.	Communicating
2.1.6 Explain the physical properties of the halogens (Group 17 elements).	Interpreting
2.1.7 Relate the electron configurations of the halogens to their chemical properties.	Interpreting
2.1.8 Describe the reactions of the halogens with water and alkalis.	Communicating
2.1.9 explain why there are differences in the acid strengths of	Interpreting

hydrogen halides	
2.2.1 Write detail electron configuration of the first row transition elements.	Communicating
2.2.2 State and describe properties of transition elements.	Communicating
2.2.3 Demonstrate through experiment, the catalytic properties of transition elements and their compounds.	Experimenting
2.2.4 describe the bonding in complex compounds	Communicating
2.2.5 Name complex compounds.	Communicating
2.2.6 Draw the shapes of complex compounds.	Drawing
2.2.7 Outline the similarities and differences between transition metals and representative (main group) metals.	Inferring
3.1.1 Explain rate of reaction.	Interpreting
3.1.2 Monitor the speed of a chemical reaction using a simple experiment.	Experimenting
3.1.3 Describe the factors that affect the rate of chemical reaction.	Communicating
3.1.4 Demonstrate experiment to show how changes in temperature affect the rate of a reaction.	Experimenting
3.1.5 Analyse and interpret simple graphs on rate of reactions	Interpreting
3.1.6 Describe the collision theory of reaction rates.	Communicating
3.1.7 Identify the role of activation energy in chemical reactions.	Communicating
3.1.8 Deduce the rate law from a given data.	Interpreting
3.1.9 Draw and analyze graphical representation for zero, first and 2nd order reactions	Inferring
3.1.10 Deduces half-life from first order reaction.	Interpreting
3.1.11 Describe the effect of temperature and catalyst on the rate constant.	Communicating
3.1.12 Deduce the rate law from an experiment.	Interpreting
3.1.13 Identify the rate determining step of a multi-step reaction.	Inferring
3.2.1 Explain reversible and irreversible reactions.	Interpreting

3.2.2 Explain that equilibrium is established when forward and reverse reactions are proceeding at the same rate.	Interpreting
3.2.3 Describe how Le Chatelier's principle can be used to predict the effect of changes in concentration, temperature and pressure on equilibrium reaction.	Communicating
3.2.4 Identify the correct equilibrium constant expression and use it in computation.	Inferring
3.2.5 Establish equilibrium for a chemical reaction from an experiment.	Experimenting
4.1.1 Outline the characteristic properties of acids and bases in aqueous solutions.	Inferring
4.1.2 Describe Arrhenius, Bronsted-Lowry and Lewis concepts of acids and bases.	Communicating
4.2.1 State the physical properties of Acids and bases.	Communicating
4.2.2 Explain the chemical properties of acids and bases and write balanced equations for the reactions.	Interpreting
4.2.3 Describe qualitatively how acid-base indicators work.	Communicating
4.2.4 Determine the quantity of an analyte in solution using titration.	Investigating
4.2.5 Draw graphs for acids base titrations.	Drawing
4.3.1 Describe and explain the difference between strong and weak acids and bases in terms of the extent of dissociation reaction with water and conductivity.	Interpreting
4.3.2 Classify acids and bases into Strong and Weak	Classifying
4.3.3 Explain the conduction of strong and weak electrolytes.	Interpreting
4.4.1 Distinguish between solutions that are acidic, neutral or basic using the pH scale.	Inferring
4.4.2 Explain pKa and pKb of weak acids and bases.	Interpreting
4.5.1 Describe a buffer solution in terms of ite composition and behaviour.	Communicating
4.6.1 Explain the term solubility.	Interpreting
4.6.2 Describe factors that affect solubility of substances.	Communicating
4.6.3 Determine the solubility and solubility product of sparingly	Calculating

soluble substances.	
4.6.4 Describe an experiment to determine the solubility product constant for Ca(OH)2.	Communicating
4.6.5 Describe the precipitation of sparingly soluble substances.	Communicating
4.7.1 Explain the meaning of salt.	Interpreting
4.7.2 State and explain how salts form acidic, alkaline and neutral aqueous solutions.	Interpreting
4.7.3 Describe the laboratory and industrial production of salt.	Communicating
4.7.4 describe the process of obtaining chemicals from brine (sea water)	Communicating
5.1.1 Describe Oxidation and Reduction Processes.	Communicating
5.1.2 Describe the types of redox reactions.	Communicating
5.1.3 Describe half reactions.	Communicating
5.1.4 Describe an experiment to illustrate reactivity of metals.	Communicating
5.1.5 Perform an experiment to illustrate the reactivity of halogens.	Experimenting
5.1.6 Describe oxidizing and reducing agents.	Communicating
5.2.1 explain the steps involved in balancing redox equations	Interpreting
5.3.1 Describe and explain the processes involved in carrying out redox titrations.	Interpreting
5.3.2 Describe an experiment to determine the end point of redox titration	Communicating
5.4.1 Describe the interconversion of chemical energy and electrical energy in redox reactions.	Communicating
5.4.2 Describe and explain the function of the standard electrode potential in redox reactions.	Interpreting
5.4.3 Describe how standard electrode potentials can be used to produce the electrochemical series.	Communicating
5.4.4 Describe and explain the functions of a simple electrochemical cell	Interpreting
5.4.5 Explain some applications of electrochemical cells	Interpreting
5.5.1 Explain the operation of electrolytic cells.	Interpreting
5.5.2 illustrate the electrolysis of brine experimentally	Experiment

5.5.3 Distinguish between electrolytic and electrochemical cells.	Communicating
5.5.4 Describe some uses of electrolysis in everyday life.	Communicating
5.5.5 Demonstrate an experiment to determine the quantity of metal deposited on an electrode.	Experimenting
5.5.6 State and explain Faraday's Laws of Electrolysis.	Interpreting
5.6.1 Explain the concept of corrosion of metals.	Interpreting
5.6.2 State and describe methods of preventing rusting	Communicating
6.1.1 Describe the electron structure of carbon.	Communicating
6.2.1 Classify organic compounds.	Classifying
6.3.1 Determine the components of a given organic compound	Calculating
6.4.1 Describe the methods of separation and purification of an organic compound from a mixture of compounds.	Communicating
6.5.1 Describe the sources and characteristics of Alkanes.	Communicating
6.5.2 Outline the nomenclature and isomerism of alkanes.	Inferring
6.5.3 Describe the preparation, physical and chemical properties of alkanes.	Communicating
6.5.4 Identify the uses of alkanes and their contribution to the greenhouse effect.	Communicating
6.6.1 Describe the sources and characteristics of alkenes.	Communicating
6.6.2 Outline the nomenclature and isomerism of alkenes.	Inferring
6.6.3 Describe the preparation and chemical reactions of alkenes.	Communicating
6.4 Outline the uses of alkenes.	Inferring
6.7.1 Describe the sources and characteristic properties of alkynes.	Communicating
6.7.2 Outline the nomenclature and isomerism in alkynes.	Inferring
6.7.3 Describe the preparation and chemical reactions of alkynes.	Communicating
6.7.4 Outline the uses and test for alkynes.	Inferring

6.8.1 Describe the structures and stability of benzene.	Interpreting
6.8.2 Outline the reactions of benzene.	Communicating
6.8.3 Explain the differences between the reactivity of benzene and alkene towards certain reagents.	Communicating
6.9.1 Describe the preparation and properties of alkanols.	Communicating
6.9.2 writes the names and structures of given alkanols.	Communicating
6.9.3 Describe the chemical reactions of alkanols.	Communicating
6.9.4 State some uses of alkanols	Communicating
6.10.1 Describe the sources, preparation and properties of alkanoic acids	Communicating
6.10.2 Write the systematic names and structures of given alkanoic acids.	Communicating
6.10.3 Describe the uses of alkanoic acids.	Communicating
6.11.1 Describe the sources, preparation and properties of alkyl alkanoates.	Inferring
6.11.2 Describe the nomenclature and structure of alkyl alkanoates.	Communicating
6.11.3 Outline the uses of alkyl alkanoates	Inferring

Author’s Construct, 2019

APPENDIX C: CLASSIFICATION OF SPECIFIC OBJECTIVES IN SHS 3

Specific Objective	Code
1.1.1 Explain the terms ‘industry’ and ‘Chemical Industry’.	Interpreting
1.1.2 Explain what a chemical plant is.	Interpreting
1.2.1 Outline the properties and reactivity of metals	Inferring
1.2.2 Explain the term mineral/ore.	Interpreting
1.2.3 Identify the different types of mineral deposits in Ghana	Communicating
1.2.4 Identify ores of gold, aluminium, iron and manganese.	Communicating
1.2.5 Outline the extraction of gold and aluminium from their ores.	Inferring
1.2.6 Outline the economic importance of Al and Au to the people of Ghana.	Inferring
1.3.1 Outline the formation of crude oil from biological sources	Inferring
1.3.2 Identify the chemical elements and compounds found in crude oil.	Communicating
1.3.3 Classify crude oil by their density, geographic location and sulphur content.	Classifying
1.3.4 Describe how crude oil is extracted from an oil well.	Communicating
1.3.5 Describe the fractional distillation of crude oil	Communicating
1.3.6 Explain cracking and reforming of organic compounds.	Interpreting
1.3.7 Outline the uses of the fractions obtained from crude oil distillation.	Inferring

1.3.8 Outline the sources and uses of petrochemicals.	Inferring
1.3.9 Explain octane number and its importance to the petroleum industry.	Interpreting
1.4.1 Explain pollution.	Interpreting
1.4.2 Describe natural air Pollution.	Communicating
1.4.3 Describe human activities that cause air pollution.	Communicating
1.4.4 Describe atmospheric events such as Acid rain, Greenhouse Effect and ozone depletion.	Communicating
1.4.5 Describe the effects of air pollution.	Communicating
1.4.6 Describe the sources of water pollution.	Communicating
1.4.7 Describe the sources of land pollution.	Communicating
1.5.1 Describe the concept of biotechnology.	Communicating
1.5.2 Outline biotechnology processes that give products for human use.	Inferring
1.5.3 Outline biotechnology services useful to humans.	Inferring
1.5.4 Visit a traditional (indigenous) industrial facility.	Investigating
1.5.5 Describe an industrial visit.	Communicating
1.6.1 Describe raw materials used in clinker and cement production	Communicating
1.6.2 Describe the process of cement production	Communicating
1.6.3 Describe the uses of cement	Communicating
1.6.4 Describe the environmental impact of cement production and usage.	Communicating
2.1.1 identify sources and properties of Fats and Oils	Communicating
2.1.2 Describe fats and oils as alkylalkanoates.	Communicating

2.1.3 Describe the preparation of soap from Fats and Oils.	Communicating
2.1.4 Compare soapy and soapless detergents	Inferring
2.1.5 Outline some uses of fats and oils.	Inferring
2.2.1 Describe the sources, and properties of proteins.	Communicating
2.2.2 Describe the general structure of alpha amino acids.	Communicating
2.2.3 Describe proteins as a natural polymer.	Communicating
2.2.4 Describe the uses of proteins.	Communicating
2.3.1 Identify the sources and properties of carbohydrates.	Communicating
2.3.2 Describe the classes and names of carbohydrates.	Communicating
2.3.3 Describe carbohydrate as a natural polymer.	Communicating
2.3.4 Describe the uses of carbohydrate	Communicating
2.4.1 Describe synthetic polymers.	Communicating
2.4.2 Describe addition and condensation polymerization.	Communicating
2.4.3 Describe how the properties of polymers depend on	Communicating
2.4.4 Explain the chemical Tests for plastics.	Interpreting
2.4.5 State the uses of polymers	Communicating

Author’s Construct, 2019

APPENDIX D: CLASSIFICATION OF WASSSCE 2012 CHEMISTRY PAPER 2

Question	Process Skill Required
1.	
(a)(i) Define electronegativity.	Communicating
(ii) State the trend of electronegativity on the periodic table.	Communicating
(b) (i) Copy and complete the following table.	Calculating
(ii) Explain briefly why	
(α) $_{11}Na^{+}$ ions are diamagnetic but $_{7}Co^{2+}$ ions are paramagnetic;	Interpreting
(β) Na^{+}, Mg^{2+} and Al^{3+} ions are isoelectronic species.	Interpreting
(c) (i) Define isotopes.	Communicating
(ii) Name two elements that exhibit isotopy.	Communicating
(d) (i) Write and balance each of the following nuclear equations:	Calculating
(ii) Identify A and B in (i)	Inferring
(d) Arrange … orbitals in order of increasing energy: 3d, 4s, 2s, 3p, 2p.	Communicating
2.	
(a) (i) Define the term solubility.	Communicating
(ii) If …	
(α) write a balanced equation for the reaction;	Communicating
(β) calculate the mass of $Ca(OH)_2$ in 25 cm^3	Calculating
…	Calculating

	(γ)	determine the solubility of $Ca(OH)_2$	Communicating
(b)	(i)	What is an acid-base indicator?	
	(ii)	Give two examples of an acid-base indicator.	Communicating
	(iii)	State which indicator(s) you would use to the end-point of …:	Communicating
	(α)	dilute hydrochloric acid against sodium hydroxide solution;	Communicating
	(β)	dilute hydrochloric acid against ammonium … solution;	Communicating
	(γ)	ethanoic acid against sodium hydroxide solution.	Classifying
(c)		Classify … as B.L acid, B.L base or Lewis acid.	Communicating
(d)		Describe briefly how the pH of … be determined in the laboratory.	

3.

(a)		Explain …	
	(i)	general formula;	Interpreting
	(ii)	homolytic fission.	Interpreting
(b)	(i)	Define hybridization.	Communicating
	(ii)	With the aid of an appropriate diagram, indicate how the $C = C$ double bond in an alkene is formed.	Interpreting
(c)		…	
	(i)	Determine the	
	(α)	empirical formula of G;	Calculating
	(β)	molecular formula of G.	Calculating
(ii)		If G reacts … deduce the structures of G and H.	Inferring
	(c)	Explain briefly why the boiling point of C_2H_5OH is 78 ^oC while that of its isomer CH_3-O-CH_3 is - 24.4 ^oC.	Interpreting

(d) Write the structure of amino acid, $CH_3CH(NH_2)COOH$	
(i) in alkaline medium;	Communicating
(ii) at isoelectric point.	Communicating
4.	
(a) (i) Describe briefly how each …bond types are formed;	
(α) dative bond;	Communicating
(β) metallic bond.	Communicating
(ii) State the type of bond in each of the following substances:	
(α) $H_2(g)$;	Communicating
(β) Na(s);	Communicating
(γ) NaH(s)	Communicating
(b) (i) Give two characteristic features of boiling.	Communicating
(ii) … atmospheric pressure on the boiling point of water?	Communicating
(iii) State two diffference between boiling and evaporation.	Communicating
(iv) (α) Arrange the following compounds in order of decreasing boiling point. $NaH_{(s)}$, $CS_{2(l)}$, , $CO_{2(g)}$.	Communicating Interpreting
(β)Explain briefly your answer in…	
(c) The table below shows the physical properties of substances Q, R and S.	
… describe how the mixture … could be separated	Inferring
…calculate the percentage by mass … in mixture	Calculating

5. (a) Consider the redox …	
(i) State the change in oxidation number of	
(α) magnesium;	Communicating
(β) hydrogen.	Communicating
(ii) Which species is being	
(α) oxidized?	Communicating
(β) reduced?	Communicating
(iii) Identify the oxidizing agent.	Communicating
(b) State the property exhibited by nitrogen (IV) oxide in each … :	
(i) $4Cu + 2NO_2 \rightarrow 4CuO + N_2$;	Communicating
(ii) $H_2O + 2NO_2 \rightarrow HNO_3 + HNO_2$.	Communicating
(c) (i) State Faradays law of electrolysis.	Communicating
(ii) Explain briefly how electrolysis affects the pH of… using …:	
(α) carbon;	Interpreting
(β) copper.	Interpreting
(iii) State two applications of electrolysis.	Communicating
(d) (i) Write the	
(α) half-cell reaction equations;	Communicating
(β) overall reaction equations.	Communicating
(ii) Calculate the volume of the gas liberated at the	
(α) anode;	Calculating
(β) cathode at s.t.p.	Calculating

6.	
(a) Consider the equilibrium … Predict the effect of each of the following changes…	
(i) concentration of Ca^{2+} is increased;	Prediction
(ii) amount of $CaCO_3$ is increased;	Prediction
(iii) amount of H_2O is increased;	Prediction
(iv) concentration of HCO_3^- is decreased.	Prediction
(v) catalyst is added.	Prediction
(b) (i) Describe briefly how pure crystals ….	Communicating
(ii) Write a balanced equation for the reaction in (i)….	Communicating
(iii) Write equations to show sulphur (IV) oxide is ….	Communicating
(c) Explain …why an aqueous solution of … pH less than 7.	Interpreting
(d) Consider the following figure:State the processes represented by A, B and C, respectively.	Inferring
(e) Arrange the three states of matter in order of decreasing	
(α) kinetic energy;	Communicating
(β) forces of cohesion.	Communicating

Author's Construct, 2019

APPENDIX E: CLASSIFICATION OF 2013 WASSCE CHEMISTRY PAPER 2

Question				Science Process Skill Required
1.				
(a)	Write the electron configuration for each…:			
	(i)	$_{13}\mathrm{Al}^{3+}$;		Communicating
	(ii)	$_{16}\mathrm{S}^{2-}$;		Communicating
	(iii)	$_{24}\mathrm{Cr}$.		Communicating
(b)	(i)	State three chemical properties of Group VII…		Communicating
	(ii)	Name the hydrides of the first two… VII.		Communicating
	(iii)	What is the common name given to the…VII?		Communicating
(c)	(i)	What is the nature of each of the following…?		
		(α)	Alpha;	Communicating
		(β)	Beta;	Communicating
		(γ)	Gamma.	Communicating
	(ii)	State two factors that determine the stability…		Communicating
(d)	(i)	Explain briefly each of the following terms:		Interpreting
		(α)	homolytic fission;	Interpreting
		(β)	heterolytic fission;	Interpreting
		(γ)	free radicals.	
	(ii)	State two characteristics of homologous series.		Communicating
2.				
(a)	Define each of the following terms:			
	(i)	closed system;		Communicating
	(ii)	endothermic reaction;		Communicating
	(iii)	heat of neutralization.		Communicating
(b)	(i)	Draw and label an energy profile diagram for		

		an endothermic reaction indicating the	Drawing
		catalyse path.	Interpreting
	(ii)	Explain briefly how a catalyst affects a…	
			Communicating
(c)	(i)	Define enthalpy of combustion.	Communicating
	(ii)	State why the enthalpy of combustion is …	
(iii)		Name the type of energy changes that occurs in each…	Communicating
	(α)	$I_{2(s)} \rightarrow I_{2(g)}$;	Communicating
	(β)	$Cl_{2(g)} \rightarrow Cl_{(g)}$;	Communicating
	(γ)	$Cl_{(g)} + e^- \rightarrow Cl^-_{(g)}$.	
(d)		Potassium, hydrogen gas and potassium hydride exhibit different types of bonds. Copy and complete the following table.	Communicating
3. (a)	(i)	What is an amphoteric oxide?	Communicating
	(ii)	Write chemical equations to show that…	Communicating
(b)		Write a balanced chemical …dilute hyrochloric acid…:	
	(i)	Zinc metal;	Communicating
	(ii)	Zinc trioxocarbonate (IV).	Communicating
(c)		Consider the following equations:(i) Which of the …is	
	(α)	a redox reaction? Give a reason…	Interpreting
	(β)	an acid-base reaction …to Lewis concept? Give a reason… your answer.	Interpreting
	(ii)	In the case of the redox reaction chosen in (c) (i) (α) above, write a balanced half … for:	Communicating
	(α)	oxidation;	Communicating
	(β)	reduction.	Communicating
	(iii)	Give a practical application of the redox ...	Communicating
(d)		A solution has a pOH of 4.5. Calculate the:	
	(i)	pH;	Calculating
	(ii)	number of hydrogen ions … in 300cm^3 …	Calculating

4. (a)	(i)	Explain briefly each of the following terms:	
		(α) polymer;	Interpreting
		(β) polymerization.	Interpreting
	(ii)	Give two examples each of the … polymers.	
		(α) natural polymer;	Communicating
		(β) synthetic polymer.	Communicating
(b)		Give the reagents and conditions needed for each …	
	(i)	$CH_3CH = CH_2 \rightarrow CH_3CH_2CH_2OH$..	Communicating
	(ii)	$CH_3CH_2CH_2\text{-}OH \rightarrow$ …	Communicating
	(iii)	$CH_3CH_2C \rightarrow$ …	Communicating
(c)		An organic compound is known to be unsaturated and monocarboxylic acid. In an experiment,… Calculate the:	
	(i)	molar mass of the compound;	Calculating
	(ii)	number of C = C bonds in a molecule …	Calculating
5. (a)	(i)	Define each of the following terms:	
		(α) rate of reaction;	Communicating
		(β) rate constant;	Communicating
		(γ) rate-determining step.	Communicating
	(ii)	State two factors that determine the rate of ….	Communicating
(b)		The following table shows the results obtained for the reaction: P + Q → R + S. If the rate = $125 [P3[Q3^{2}$, calculate…	
	(i)	values of x y and z;	Calculating
	(ii)	overall order of the reaction.	Calculating
(c)	(i)	Arrange the following compounds ... $MgCl_2$, NaCl, $AlCl_3$.Give reasons…	Interpreting
	(ii)	Explain briefly why an aqueous solution of iron (II) tetraoxosulphate (VI) turns brown on standing.	Interpreting
6. (a)		Explain briefly why a given mass of sodium hydroxide	

		pellets cannot be used to prepare a standard solution.	Interpreting
(b)	(i)	List two chemicals used in the laboratory …	Communicating
	(ii)	Write a balanced equation for the laboratory …	Communicating
	(iii)	Mention a chemical that can be used …(b) (i).	Communicating
	(iv)	Name … collection of the gas. Give a reason ..	Communicating
	(iv)	List two physical properties of…gas.	Communicating
(c)	(i)	State Dalton’s law of partial pressures.	Communicating
	(ii)	A mixture of gases with total pressure … and 0.025 moles of oxygen at 25^{o}C. Calculate the	
		(α) total volume of the gaseous mixture;	Calculating
		(β) partial pressure of hydrogen in ...	Calculating
(d)	(i)	Give two reasons why real gases deviate….	Interpreting
	(ii)	List the two conditions … a real gas… ideally.	Communicating

Author’s Construct, 2019

APPENDIX F: CLASSIFICATION OF 2014 WASSCE CHEMISTRY PAPER 2

Question	Science Process Skill Required
1.	
(a) (i) Define ionic bond.	Communicating
(ii) What types of bond exist in	
(α) magnesium oxide;	Communicating
(β) ammonium ion?	Communicating
(b) Give three ions which are isoelectronic with neon.	Communicating
(c) Define Arrhenius acid.	Communicating
(d) State the function of H_2SO_4 in the following equations:	
(i) $C_{(s)} + \text{conc.}H_2SO_4 \rightarrow CO_{(g)} + SO_{2(g)} + H_2O_{(l)}$	Communicating
(e) Calculate the amount of silver deposited in moles…	Calculating
(f) State two effects of pollution.	Communicating
(g) Describe briefly … of biogas using a biogas generator.	Communicating
(h) State one use of each … chemical industry:	
(i) hydrogenation of vegetable oil;	Communicating
(ii) cracking;	Communicating
(iii) esterification.	Communicating
(i) Determine the oxidation state of manganese in MnO_4^-.	Calculating
(j) Aluminium metal reacts with dilute hydrochloric acid to liberate hydrogen gas. Write a balanced equation …	Communicating
2.	
(a) An element R has atomic number of 12.	
(i) Draw its electron configuration.	Drawing
(ii) Determine the charge on its ion.	Inferring
(iii) Write the formula of the compound formed between R and chlorine.	Inferring
(iv) State the,	

	(α) group of R,	Communicating
	(β) period of R in the periodic table.	Communicating
	(v) Explain briefly your answer in (iv).	Interpreting
(b)	(i) Arrange the … order of decreasing ionization energy: potassium, lithium, sodium.	Communicating
	(ii) Give reasons for your answer in (b) (i).	Interpreting
(c)	When … is exposed to air it decomposes.	
	(i) Write a balanced equation for the reaction.	Communicating
	(ii) Using manganese (IV) oxide as catalyst, outline an experiment to illustrate …	Experimenting
(d)	A 50cm^3 solution of a 0.02 mol dm^{-3} hydrochloric acid …Determine the pH of the resultant solution.	Calculating
3. (a)	In an experiment, … $R = k [M]^2 [N]$ …Deduce how…:	
	(i) the concentration of M is halved but that of N …	Calculating
	(ii) the concentration of M is doubled and that of N …	Calculating
(b)	(i) What is the standard electrode potential?	Communicating
	(ii) List two uses of standard electrode potential values.	Communicating
(c)	Concentration sodium chloride solution was …	
	(i) Which ion would be discharged at the	
	(α) anode,	Communicating
	(β) cathode?	Communicating
	(ii) Write balanced equations for the discharge…	Communicating
	(iii) State the effect of the resulting …	Communicating
	(iv) State two industrial applications ….	Communicating
(d)	Consider the following equilibrium reaction:	
	$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$ $\Delta H = -$ ve…	
	(i) Copy and complete the following table.	
	(α)	
	(β)	Predicting
	(γ)	Predicting
	(δ)	Predicting

			Predicting
(ii) Name the principle used in completing the table in (d) (i).			
(iii) State the principle named in (d) (ii).			
			Communicating
			Communicating
4(a) State two differences between hydration and hydrolysis.			
(b)	(i)	Explain briefly the term titration	Interpreting
	(ii)	The following pH changes were measured …	Interpreting
	(α)	Draw a graph of these results with pH on …	
			Drawing
(β)	Describe the shape of the curve in (b) (ii) (α).		
(c)	(i)	State two sources of errors during …	
	(ii)	List two applications of titration in the…	Communicating
(d)	(i)	What is standard solution?	Communicating
	(ii)	Describe briefly how a standard solution …	Communicating
			Communicating
			Communicating
5. (a)	(i)	Define the term isomerism.	Communicating
	(ii)	Describe briefly the bonding within…	Communicating
	(iii)	What would you observe …reagents:	
		(α) neutral $KMnO_{4(aq)}$;	Communicating
		(β) bromine water.	Communicating
(b)	(i)	Define the term fats.	Communicating
	(ii)	(α) Describe briefly the production…soap.	Communicating
		(β) Write a balanced equation for the…	Communicating
		(γ) Name the by-product of the processes…	Communicating
(c)	State what you would observe when freshly …few days.		Communicating

Author's Construct, 2019

APPENDIX G: CLASSIFICATION OF 2015 WASSCE CHEMISTRY PAPER 2

Question			Science Process Skill Required
1.			
	(a)	Define esterification.	Communicating
	(b)	State two properties of plastic.	Communicating
	(c)	Name the components of duralumin.	Communicating
	(d)	What is meant by each of the following terms?	
		(i) raw material;	Communicating
		(ii) primary product.	Communicating
	(e)	State Charles' law.	Communicating
	(f)	List four pieces of protective equipment…	Communicating
	(g)	Give two uses of ammonia.	Communicating
	(h)	Name the:	
		(i) process by which lighter hydrocarbons …	Communicating
		(ii) products formed from the reaction ….	Communicating
	(i)	Determine the oxidation number of sulphur…	Communicating
	(j)	Write the IUPAC name for each …	
		(i) $NaClO_3$;	Communicating
		(ii) $CuSO_4.5H_2O$.	Communicating
2.			
	(a) (i)	Which of the elements:	
		(α) is a halogen?	Inferring
		(β) is most likely to be attracted	
		negative…?	Inferring
		(λ) belongs to group I?	
		(δ) would …form an ion with a	Inferring
		double..?	Inferring
	(ii)	What type of bond would exist between J and X…?	
			Inferring

	(iii) How many neutrons are there in Q?	
	(iv) Write the formula … when R combines with X.	Calculating
	(v) State the element which exists as diatomic	Inferring
	molecule.	
		Inferring
(vi) Select the element which belongs to the *d*-block…		
		Inferring
(b)	(i) Explain briefly the term *atomic orbital*.	
	(ii)(α) State three postulates of Dalton's atomic	Interpreting
	theory.	
	(β) List two limitations of this theory in the	Communicating
	study…	
	(iii) Describe briefly the structure of sodium …	Communicating
(c)	A sample of carbon is burnt at a rate of 0.50 g per …	Communicating
	(i) Write a balanced equation for the reaction.	
	(ii) Determine the:	Communicating
	(α) volume of carbon (IV) oxide produced …	
	(β) moles of oxygen used up in the process	Calculating
	…	
		Calculating
3. (a)	(i) Give three characteristics of homologous	
	series.	Communicating
	(iii) Name two groups of compounds which	Communicating
	form ….	
(b)	A saturated organic compound A containing two	
	carbon atoms reacted with ethanoic acid in the	
	presence…	
	(i) Name the functional group present in A.	Inferring
	(ii) Draw the structure of A.	Drawing
(iii)	Write a chemical equation to show the formation of	
	B.	Inferring
	(iv) Name the compound B.	Inferring
(c)	(i) Write a balanced equation for the reaction ...	Communicating
	(ii) Give IUPAC name of the product …	Communicating

	(iv)	State two conditions under which	Communicating
		cracking…	Communicating
(d)	(i)	Outline the preparation of ethanol …	Communicating
	(ii)	Give two properties of starch.	Interpreting
	(ii)	Give a reason why starch does not	Communicating
		reduce…	
	(iii)	Describe briefly a chemical test …of starch.	
4(a)	(i)	Describe briefly how gold is extracted …	Communicating
	(ii)	List the impurities in the ore.	Communicating
	(iii)	Outline how the gold obtained from	Communicating
(b)	(i)	Define *Bronsted-Lowry base*.	Communicating
	(ii)	Calculate the pH of 0.01 mol dm^{-3} sodium …	Calculating
	(c)	In the production of tetraoxosulphate…	
	(i)	two sources of sulphur.	Communicating
	(ii)	the catalyst used.	Communicating
	(iv)	the product formed when $SO_{2(g)}$ is	Communicating
		absorbed…	
(d)		If 3.08 g of Fe completely reacted with 50.0 cm^3 …	
	(i)	write an equation for the reaction;	Communicating
	(ii)	calculate the relative atomic mass of Fe.	Calculating
5. (a)	(i)	Carbon $^{14}_{6}C$ undergoes β-emission … nuclide	
		M.	Calculating
		Write an equation to illustrate the change.	
	(ii)	$^{226}_{88}$Ra successively loses three α-particles	
….			Calculating
	(α)	Calculate the mass number and…	
	(β)	Write out the formula of N.	Inferring
(b)		Consider the following equation:...	
		List three ways by which the rate ..	
		increased.	Inferring
(c)	(i)	Explain briefly an equilibrium reaction.	
	(ii)	Consider the reaction represented …	Interpreting

	equation: $2NO_{(g)} \rightleftharpoons N_{2(g)} + O_{2(g)}$; $\Delta H = -90$ k J mol^{-1}.	
	(α) Write an expression for the…, Kc.	Communicating
	(β) Sketch an energy diagram ... reaction.	Drawing
	(λ) State with reason the effect of decrease in temperature on the equilibrium position …	Interpreting

Author's Construct, 2019

APPENDIX H: CLASSIFICATION OF 2016 WASSCE CHEMISTRY PAPER 2

Question		Science Process Skill Required
1. (a)	What are nucleons?	Communicating
(b)	State Graham's law of diffusion.	Communicating
(c)	Explain briefly why aluminium does not corrode easily?	Interpreting
(d)	State three examples of periodic properties.	Communicating
(e)	State two reasons why real gases deviate from ideal …	Interpreting
(f)	List three uses of fractional distillation in industry.	Communicating
(g)	What factors determine the selective discharge …?	Communicating
(h)	State the type of reaction represented by each ….	
	(i) $C_2H_6 + Br_2 \rightarrow C_2H_5Br + HBr$;	Communicating
	(ii) $C_2H_6 + Br_2 \rightarrow C_2H_5Br$	Communicating
(i)	Name the products formed when butane burns …	Communicating
(j)	List three methods of separating a solid from a liquid…	Communicating
2.		
(a)	Consider the following atoms: ...	
(i)	State the phenomenon exhibited by the two atoms.	Inferring
(ii)	What is the difference between the atoms.	Inferring
(iii)	Give two examples of elements that exhibit the …	Communicating
(iv)	If T is 17, write the electron configuration …	Communicating
(b)	(i) State two differences between metals and …to their:	
	(α) physical properties;	Communicating
	(β) chemical properties.	Communicating
	(ii) Give one example of each of the following…:	
	(α) an emphoteric oxide;	Communicating
	(β) a hydride which evolves	

hydrogen…;	Communicating
(γ) a trioxocarbonate (IV) salt which is…	Communicating
(δ) a chloride salt which is readily…	Communicating
(c) (i) State three characteristics properties of …:	Communicating
(ii) Write the electron configuration of $_{30}Zn$.	Communicating
(iii) Explain briefly why zinc is not considered as a typical…	Interpreting
(d) Consider the reaction represented by the following equation: Calculate the mass of sodium trioxocarbonate (IV) needed to…	Calculating
3. (a) (i) Define structural isomerism.	Communicating
(ii) State the class of alkanols to which each …:	
(α) $CH_3C(CH_3)_2OH$;	Communicating
(β) $CH_3CH(CH_3)CH_2OH$;	Communicating
(γ) $CH_3CH_2CH(CH_3)OH$.	Communicating
(b) (i) Write the formulae of the product(s) formed…:	
(α) CH_3CH_2COOH …C_4H_9OH, heat	Communicating
(β) CH_3CH_2COOH … Conc. H_2SO_4	Communicating
(γ) $CH_3CH_2CH_2CH_2OH$… H^+/KMnO4…	Communicating
(ii) Name the major product(s) of each of the …(b)(i).	Communicating
(c) A gaseous hydrocarbon R of mass 7.0 g occupies a volume of 2.24 dm^3 at s.t.p. If … determine its:	
(i) empirical formula;	Calculating
(ii) molecular formula.	Calculating
(e) Draw the structures of the isomers of the alkene with… C_4H_8.	Communicating
4(a) Define the term solubility.	Communicating
(b) The table below gives the solubilities… P and Q at…	

	(i) On the same axes, plot the graphs of solubility …,	Drawing
	(α) state the solubility of P at 50^{o}C;	Interpreting
	(β) state the temperature at which the solubility of Q …	Interpreting
	(γ) calculate … of P … if… P is cooled…0^{o}C to 30^{o}C.	Calculating
(c)	The melting and boiling points of sodium chloride are 801^{o}C and 1413^{o}C, respectively. Explain briefly …	Interpreting
(d)	(i) Define each of the following terms:	
	(α) nuclear fusion;	Communicating
	(β) nuclear fission.	Communicating
	(ii) State one factor that affects the stability …	Communicating
(e)	Consider the …substances: $AlCl_3$, OH^-, NH_3 and H_3O^+.Classify each … as nucleophiles or electrophiles.	Classifying
5. (a)	(i) What is a buffer solution?	Communicating
	(ii) Calculate the pH of a solution containing…	Calculating
	(iii) Indicate whether the solutions is acidic or basic.	Inferring
	(iv) Give one reason for your answer in (a)(iii).	Interpreting
(b)	… table shows the pH ranges of … indicators K, L and M.	
	Select the indicator(s) which would be suitable for titrating:	
	(i) strong acid with strong base;	Predicting
	(ii) strong acid with weak base;	Predicting
	(iii) weak acid with strong base.	Predicting
(c)	(i) An aqueous solution of iron (II) can be… Write a balanced ionic equations for the:	
	(α) oxidation half reaction;	Communicating
	(β) reduction half reaction.	Communicating
	(ii) Describe briefly how pure dry crystals …	Communicating
(d)	(i) Name the process involved in the	

	production…	Communicating
(ii)	Consider the following salts: KNO_3, CH_3COONa, NH_4, Cl Which one…	
	(α) an acidic solution?	Inferring
	(β) a neutral solution?	Inferring
(iv)	Excess dilute hydrochloric acid was added to 1.50 g of calcium trixocarbonate (IV) and … Calculate the rate …	Calculating

Author's Construct, 2019

APPENDIX I: DEFINITIONS OF SCIENCE PROCESS SKILLS

Science process skills	**Definition**
Observing	Using the senses to make accurate observations.
Calculating	Using formula or algorithms to solve problems
Drawing	Drawing clearly and label specimens, objects etc.
Recording	Accurately noting down relevant observations, procedures or inferences for reporting
Classifying	Group specimens and objects according to their common properties or characteristics.
Communicating	Ability to present pertinent and precise ideas, concepts, reports on projects undertaken. Reports, oral or written, concise, clear and accurate.
Measurement:	Using measuring instruments and equipment for measuring, reading and making observations
Inferring	Making an educated guess about an object or event based on previously gathered data or information
Predicting	Stating the outcome of future event based on a pattern of evidence
Interpreting	Organising data and drawing conclusion from it, explaining
Defining operationally	Stating how to measure a variable in an experiment.
Manipulation:	Skilful handling of scientific objects and tools for accomplishing specific tasks. It involves setting up laboratory apparatus, preparing specimens and other material for observation.
Formulating models	Creating a mental or physical model of a process or event.
Experimenting	Manipulating equipment or materials to change variables for observations leading to specific inferences or conclusion
Hypothesising	Stating the expected outcome of an experiment
Controlling variable	Being able to identify variables that can affect experimental outcome, keeping most constant while manipulating only the independent variable

Author's Construct, 2019

APPENDIX J: QUESTIONNAIRE FOR TEACHERS AND STUDENTS ON SCIENCE PROCESS SKILLS.

UNIVERSITY OF CAPE COAST
DEPARTMENT OF SCIENCE EDUCATION
QUESTIONNAIRE ON SCIENCE PROCESS SKILLS

Dear Respondents, this study is purely for academic purposes. You will be contributing to its success if you answer the item as frankly and honestly as possible. Please provide your correct responses to the questions below in order to reflect your view. Thank you.

Tick two to indicate your status

	Tick
Male	
Female	
Teacher	
Student	

If you are a teacher, please indicate how long you have been teaching: ……………………

Questions 1. Which of the following activities have you ever engaged in to help you understand, develop scientific skills and solve scientific problems? Tick to show how often you engage in the activities.

	Always	Most of the time	Some of the time	Not quite often	Never engage in it
Reading scientific books and journals					
Talking, discussing and debating scientific issues					
Doing laboratory work					
Field trips					
Writing about science					
Project work					

Case studies					
Representing scientific ideas using symbols and mathematics					

Question 2. Please tick the following to indicate their importance in the teaching and learning of science at the SHS level.

	Very important	Important	Moderately important	Of little important	Unimportant
Understanding of scientific concepts					
Science process skills					
Scientific attitude					

Question 3: Please tick the skills in the table according to their importance for science education at the SHS level.

Scientific skills	Very important	Important	Moderately important	Of little important	Unimportant
Interpreting data: graphs and tables					
Understanding basic statistics					
Questioning: raising questions that are testable, measurable and repeatable					
Observing (and comparing): proficiency in describing patterns, ordering and sequencing events					
Interpreting data: ability to construct an argument from data					

Ability to create a testable hypothesis					
Measuring: understanding concepts of accuracy and precision					
Ability to design an experiment: identifying and controlling variables					
Problem solving/critical thinking					
Recording and communicating information: understanding forms of information or data representation (i.e., verbal, written, pictorial and mathematical					
Classification: grouping and organising objects or attributes					
Predicting: forecast future observations on the basis of present trends or previous knowledge					
Being able to infer plausible reasons for failed experiments					
Creating appropriate graph from data					

Question 4: Please tick the skills in the table according to how often they are developed at the SHS level.

Scientific skills	Always	Most of the time	Some of the times	Not quite often	Never
Interpreting data: graphs and tables					
Understanding basic statistics					
Questioning: raising questions that are testable, measurable and repeatable					
Observing (and comparing): proficiency in describing patterns, ordering and sequencing events					
Interpreting data: ability to construct an argument from data					
Ability to create a testable hypothesis					
Measuring: understanding concepts of accuracy and precision					
Ability to design an experiment: identifying and controlling variables					
Problem solving/critical thinking					
Recording and communicating information: understanding forms of information or data representation (i.e., verbal, written, pictorial and mathematical forms)					
Classification: grouping and organising objects or attributes					
Predicting: forecast future observations on the basis of present trends or previous knowledge					
Being able to infer plausible reasons for failed experiments					
Creating appropriate graph from data					

Question 5: If you are to choose (tick) only 4 of the following skills which ones would you focus on, as ***the most important*** for YOU to acquire?

Scientific skills	Most important (Tick 4)
Interpreting data: graphs and tables	
Understanding basic statistics	
Questioning: raising questions that are testable, measurable and repeatable	
Observing (and comparing): proficiency in describing patterns, ordering and sequencing events	
Interpreting data: ability to construct an argument from data	
Ability to create a testable hypothesis	
Measuring: understanding concepts of accuracy and precision	
Ability to design an experiment: identifying and controlling variables	
Problem solving/critical thinking	
Recording and communicating information: understanding forms of information or data representation (i.e., verbal, written, pictorial and mathematical forms)	
Classification: grouping and organising objects or attributes	
Predicting: forecast future observations on the basis of present trends or previous knowledge	
Being able to infer plausible reasons for failed experiments	
Creating appropriate graph from data	

Question 6: Which of the following skills are ***the least important*** for YOU to acquire? Please choose (tick) any four below.

Scientific skills	Least important (Tick 4)
Interpreting data: graphs and tables	
Understanding basic statistics	
Questioning: raising questions that are testable, measurable and repeatable	
Observing (and comparing): proficiency in describing patterns , ordering and sequencing events	
Interpreting data: ability to construct an argument from data	
Ability to create a testable hypothesis	
Measuring: understanding concepts of accuracy and precision	
Ability to design an experiment: identifying and controlling variables	
Problem solving/critical thinking	
Recording and communicating information: understanding forms of information or data representation (i.e., verbal, written, pictorial and mathematical forms)	
Classification: grouping and organising objects or attributes	
Predicting: forecast future observations on the basis of present trends or previous knowledge	
Being able to infer plausible reasons for failed experiments	
Creating appropriate graph from data	

Authors' Construct, 2019

APPENDIX K: STUDENTS' DEVELOPMENT OF SCIENCE PROCESS SKILLS (SDSPS) TEST

UNIVERSITY OF CAPE COAST
DEPARTMENT OF SCIENCE EDUCATION
QUESTIONNAIRE ON SCIENCE PROCESS SKILLS

Dear Respondents, this study is purely for academic purposes. You will be contributing to its success if you answer the item as frankly and honestly as possible. Please provide your correct responses to the questions below in order to reflect your view. Thank you.

Tick to indicate your status

	Tick
Male	
Female	

INSTRUMENT TO ASSESS ACQUISITION OF SCIENCE PROCESS SKILLS

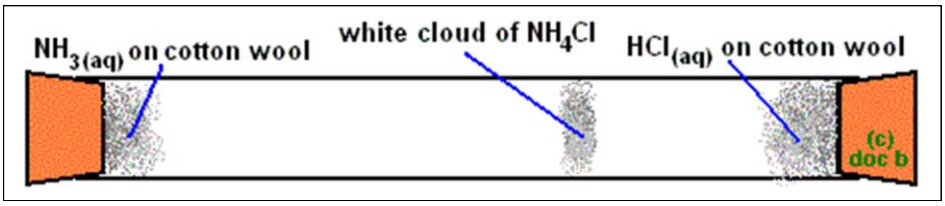
Circle the letter of the most appropriate answer

1. When chlorine gas is passed through colourless potassium iodide solution, dark iodine solid is produced. How would you observe that the reaction has occurred?

A. You will see iodine solid
B. You will see colour change
C. You will feel precipitation of iodine
D. You will smell displacement of iodine

2. Which of the following could be observed with the sense of sight?

A. The temperature of the air
B. Precipitation of salt
C. The sweetness of a new chemical
D. The smell of perfume



3. Study the diagram above carefully. Which of the particles in the substances below travel fastest?

A. The particles in the ammonium chloride
B. The particles in the acid
C. The particles in the ammonia
D. The particles in the cotton wool

4. Ammonia is a colourless and smelly gas. The presence of ammonia in a cotton wool can easily be identified because

A. The hydrogen in the ammonia gives a pop sound
B. It becomes white cloud when it meets the acid
C. You can smell it
D. You can see its gaseous state

5. A certain hairdresser straightens the hair of her clients with homemade relaxer. She prepares the relaxer by mixing petroleum gel with standard caustic soda solution. What unit would best be used for the caustic soda she weighed with an electronic balance?

A. Kilograms
B. Decimetre cube
C. Grams
D. Litres

6. Hydrogen gas can be produced by reacting zinc with acid. Ama wants to produce some gas and test for pop sound using a lighted splint. Estimate the volume of acid she needs to add to the zinc in the test tube.

A. About 5μL
B. About 5 dm^3

C. About $5m^3$

D. About 5mL

7. Kofi needs $25cm^3$ of certain solution. Which of the following did he used to measure the solution accurately?

A. Electronic balance

B. Pipette

C. Volumetric flask

D. Measuring cylinder

8. A nurse measures hotness of her patient's body in order to diagnose fever. Which of the following does the nurse use accurately in the hospital?

A. The nurse's palm

B. Thermometer

C. Fever metre

D. Degree of hotness chart

Halogen	Physical state	Appearance	Reaction with alkali metal
F_2	Gas	Pale yellow	Reacts
Cl_2	Gas	Pale green	Reacts
Br_2	Liquid	Dark red	Reacts
I_2	Solid	dark	Reacts

Study the table above carefully:

9. Which of the categories in the table above can put the halogens into two (2) groups?

A. Halogen

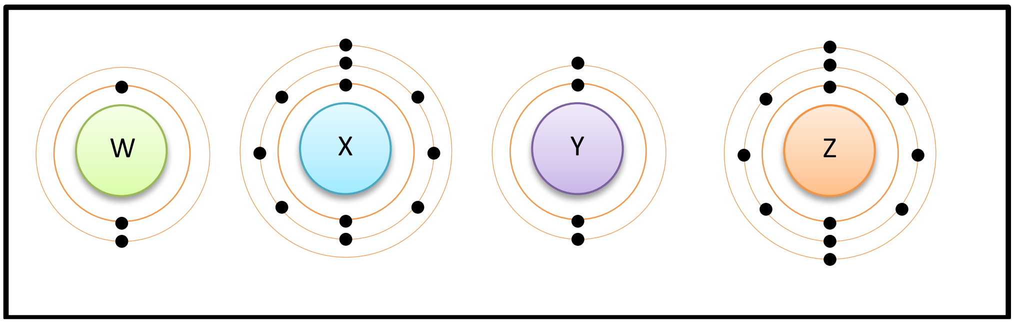
B. Physical state

C. Appearance

D. None of the options given

10. Which of the categories cannot be separated into more groups?

A. Halogen
B. Physical state
C. appearance
D. Reaction with alkali metals
E.



Structures of four different atoms showing electrons on their shells

11. Which of the following pair in the diagram above cannot be put in the same category?
A. W and X
B. W and Z
C. Y and Z
D. Z and X

12. What feature(s) of W and Y as shown in their atomic structures put them into the different category?
A. Number of shells
B. Number of electrons on the inner shell
C. Number of electrons on the outer shell
D. Number of electrons

13. A bottle containing a liquid has the label highly inflammable. The content of the bottle was exposed to a naked flame. Which of the following happened?
A. The bottle caught fire
B. The hand of the holder got corroded
C. Reaction occurred in the bottle
D. There was exothermic reaction

Reagent	$SO_4^{2}{}_{-(aq)}$	$Cl^{-}_{(aq)}$
$Ba^{2+}_{(aq)}$	Insoluble white solid	Soluble
$Ag^{+}_{(aq)}$	Soluble	Insoluble white solid

14. After studying a table like the one above, Kofi added barium chloride and hydrochloric acid to an unknown clear solution and produced a white precipitate. Which of the following is the correct inference made by Kofi?

A. The solution may contain barium and sulphate ions.

B. The solution may contain silver and chloride ions

C. The solution may contain silver or chloride ions

D. The solution may contain sulphate or silver ions

15. Atmospheric oxygen and microbes in air can oxidise ethanol in beer into ethanoic acid. Ethanoic acid has a sharper taste than ethanol. People usually beat their chest after drinking local beer exposed to the atmosphere. Which of the following can be inferred from this phenomenon?

A. Local beer is made from ethanoic acid

B. Some local manufacturers use nails to brew local beer

C. Some of the ethanol in the local beer is converted into ethanoic acid

D. ethanol content in the local beer becomes more concentrated

16. A report was made of an almost fatal chemistry laboratory accident that seriously injured about 16 students and a teacher. The forensic investigation revealed broken glasses from a large water glass bowl with a splash of water all over the lab. Potassium metal reacts explosively with water. Predict how the accident might have occurred

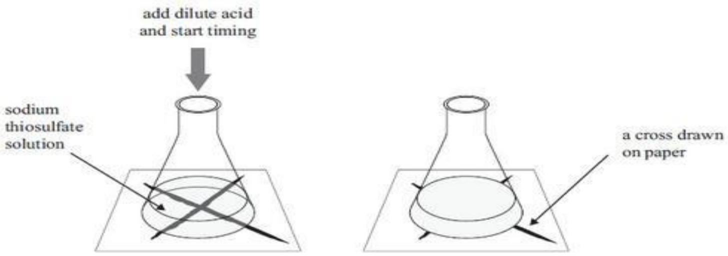
A. The gas from the gas cylinder exploded

B. A student accidently hit the glass bowl full of water with a large metal

C. The teacher failed to take precaution

D. The teacher accidentally added large chunk of potassium into the water in the bowl

17. A chemistry student is identifying the type of ions in four (4) specimens labelled A, B, C and D. The student performs different tests on each sample then observations and inferences are made. Which is the best way to show the tests, observations and inferences made by the student?
A. Numbers
B. Graphs
C. Tables
D. Images



18. Dilute hydrochloric acid reacts with sodium thiosulphate to produce solid sulphur which clouds the resulting solution. Dilute acid at different temperatures were used and the time it took for the cross under the glass as shown in the diagram to disappear was measured. What is the best way to communicate the relationship between the temperatures of the acid and the time recorded in the experiment?
A. Graphs
B. Numbers
C. Tables
D. Images

19. Which of the following pairs can be used to report the result of the experiment above?
A. Numbers and Graphs
B. Tables and graphs
C. Images and numbers
D. None of the above

20. You are asked to investigate the number of practical work done by 20 different schools in an academic year. What is the best way to communicate your findings?

A. Numbers

B. Graphs

C. Tables

D. Images

21. A student wants to investigate how the temperature of an acid affects how quickly sulphur is produced from sodium thiosulphate. Which of the following should be held constant?

A. Concentrations of the acid and the thiosulphate used

B. The temperatures of the acid

C. The time taken for sulphur to appear

D. All the options

22. During titration of strong base against strong acid, the following will not be one of the factors that can determine the titre value.

A. Volume of the base pipetted

B. The type of indicator used

C. The initial reading of the burette

D. All the options will not affect the titre value

23. The rate of decomposition of hydrogen peroxide depends on factors such as concentration, temperature and surface area of the manganese oxide used as a catalyst. Which of the following indicates a well controlled experiment to show the effect of surface area?

A. The same size of manganese oxide is placed in the same volume of peroxide taken from the same stock each time the experiment is repeated

B. Different sizes of manganese oxide is placed in the same volume of peroxide taken from the same stock

C. Different sizes of manganese oxide is placed in different volume of peroxide taken from the same stock

D. Same sizes of manganese oxide is placed in the same volume of peroxide taken from different stock

The table below shows the yield of ammonia obtained by Kofi at different temperatures and pressure.

Pressure (Atm.)	**Percentage yield of ammonia at equilibrium**				
	Temperature (^oC)				
	100	200	300	400	500
10	88.2	50.7	14.7	3.9	1.2
25	91.7	63.6	27.4	8.7	2.9
50	94.5	74.0	39.5	15.3	5.6
100	96.7	81.7	52.5	25.2	10.6
200	98.4	89.0	66.7	38.8	18.3

24. Which factor(s) will you increase to increase the equilibrium yield of ammonia?

A. Temperature
B. Pressure
C. Pressure and temperature
D. None of the above

25. From Kofi’s evidence which of the following conditions produced the least yield of ammonia?

A. Low pressure and high temperature
B. High pressure and low temperature
C. Medium pressure and low temperature
D. Low pressure and medium temperature

26. At what temperature is the highest yield obtained?

A. 100^oC

B. 200^oC

C. 300^oC

D. 400^oC

27. Which pressure produced 39.5% yield of ammonia?

A. 10 Atm.

B. 50 Atm.

C. 100 Atm.

D. 25 Atm.

28. Which temperature and pressure produced 66.7% yield of ammonia?

A. 300^oC and 200 Atm.

B. 200^oC and 300 Atm.

C. 100^oC and 400 Atm.

D. 400^oC and 100 Atm.

29. Which of the following statements will you use to carry out further investigations to either confirm or falsify Kofi's evidence above?

A. More ammonia is produced at high pressure

B. More ammonia is produced at high temperature

C. More ammonia is produced at low pressure

D. A catalyst is required to produce more ammonia

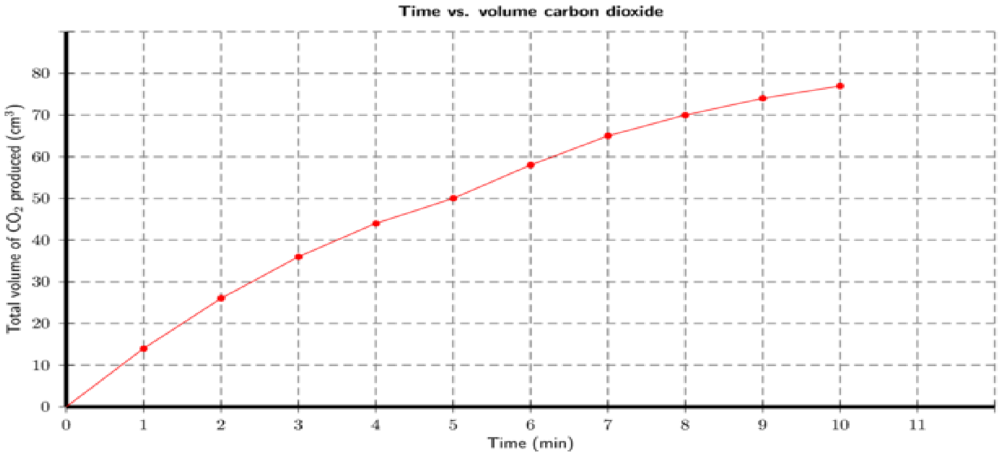
30. A baker accidentally added more baking powder than usual to her bread and noticed that the bread became very soft. Which of the following statements are testable from the baker's experience?

A. Bread becomes soft when baking powder is added accidentally

B. Bread dough rises quickly with baking powder

C. More baking powder makes the bread softer

D. None of the above



31. A group of students performed an experiment using carbonate to produce carbon dioxide. The volume of carbon dioxide produced over 10 minutes is presented as in the figure above. Which of the testable statements can be generated from the students' evidence?

A. More carbon dioxide is produced when the reaction is allowed to proceed for long time

B. Less carbon dioxide is produced when the reaction is allowed to proceed for a long time

C. Amount of carbon dioxide produced per unit time decreases with increasing time

D. None of the above

32. The students realised that any time they increased the mass of the carbonate used, the volume of the gas produced over 10 minutes also increased. Which of the following hypothesis can be derived from this evidence?

A. The rate of the reaction depends only on the increased mass of the carbonate

B. The rate of reaction increases when the amount of the reactant increases

C. The rate of the reaction increases when the surface area of the carbonate is increased.

D. The rate of the reaction changes only when the amount of carbonate is changed

33. Ama thinks that the more baking powder in bread the softer it becomes. Which of the following suggests how Ama can test her idea?

A. Put different amount of baking powder in a specified amount of bread ingredients and bake at different temperatures over the same period of time.
B. Put different amount of baking powder in a specified amount of bread ingredients and bake at the same temperature over the same period of time
C. Put the same amount of baking powder in a specified amount of bread ingredients and bake at the same temperature over the different period of time
D. Put the same amount of baking powder in a specified amount of bread ingredient and bake at different temperature over the same period of time.

34. Ekua wanted to test the density of different gases. She produced different gases into the same type of balloons under the same condition and tested them on different days by measuring the height the gases rose to in the air. Abban had the view that the test was not fair and that the test could be done on the same day. Which of the following justifies Abban's claim?
A. All gases rise in air
B. Conditions of the gases in the balloon affect the density of air differently
C. Air conditions affect the density of gases
D. Air conditions are the same all the time.

35. A conditioner used to prevent scalp burning contains petroleum gel and an indicator which changes colour when the alkali in the relaxer meets the conditioner at the scalp of the client. The scientific way of testing that the indicator in the product is responsible for the colour change is?
A. Applying the product on 20 people
B. Applying a different product on 10 people and the product on the remaining 10 people
C. Applying the product on 10 people and indicator on the remaining 10 people
D. Applying the product on 10 people and petroleum gel on the remaining 10 people.

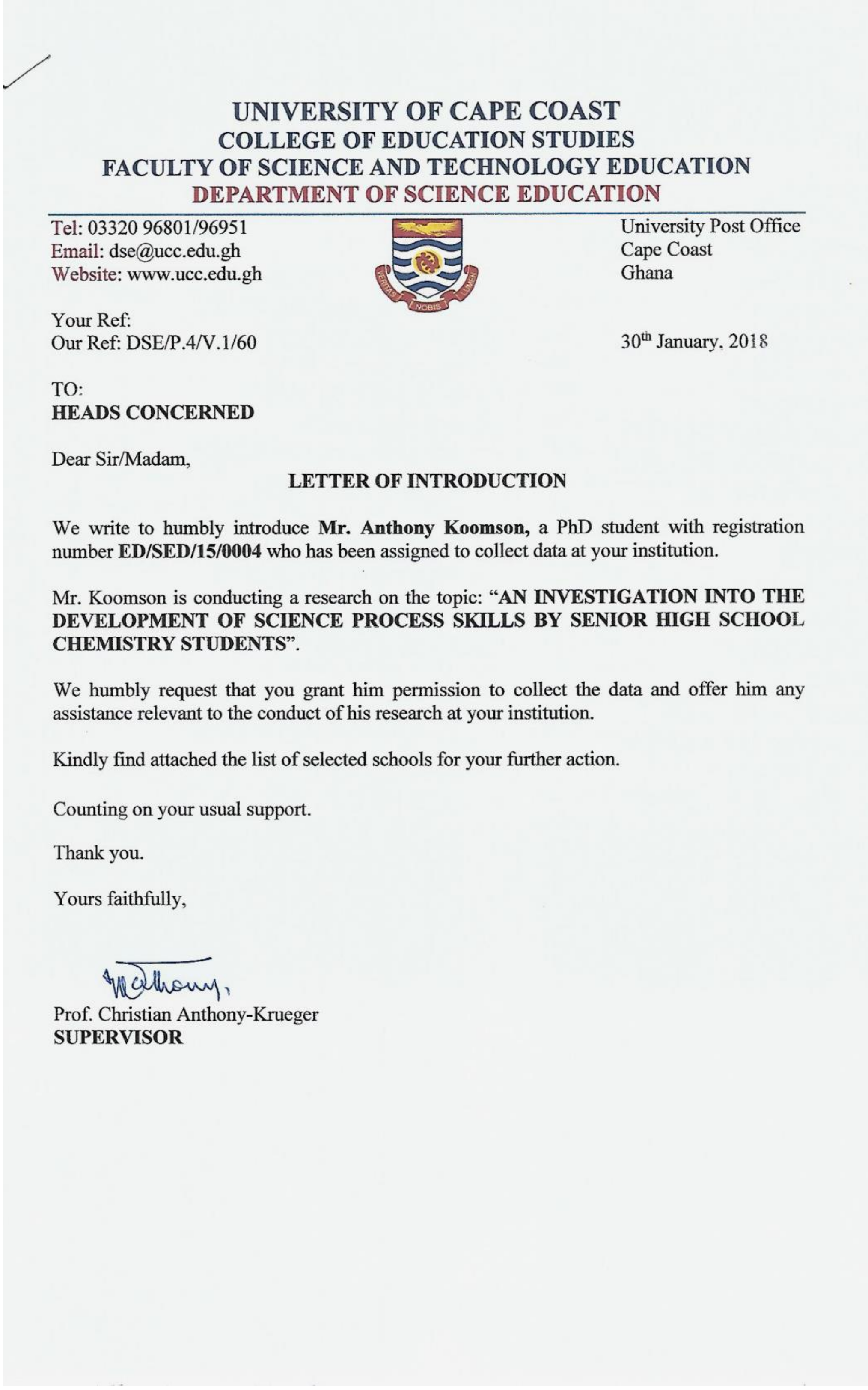
36. A student wants to know the effect of acid rain on fish population. He takes two jars and fills each of the jars with the same amount of water. He adds fifty drops of vinegar (acid) to one jar and adds nothing extra to the other. He then put 10 similar fish in each jar. Both groups of the fish are cared for in the same

way. After observing the behaviour of the fish for a week, he makes his conclusion. What would you suggest to improve this experiment?

A. Prepare more jars with different amounts of vinegar
B. Add more fish to the two jars already in use
C. Add more jars with different kinds of fish and different amount of vinegar in each jar
D. Add more vinegar to the jars already in use

Author' Construct, 2019

APPENDIX L: LETTER OF INTRODUCTION



UNIVERSITY OF CAPE COAST
COLLEGE OF EDUCATION STUDIES
FACULTY OF SCIENCE AND TECHNOLOGY EDUCATION
DEPARTMENT OF SCIENCE EDUCATION

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University Post Office
Cape Coast
Ghana

Your Ref:
Our Ref: DSE/P.4/V.1/60

30th January, 2018

TO:
HEADS CONCERNED

Dear Sir/Madam,

LETTER OF INTRODUCTION

We write to humbly introduce **Mr. Anthony Koomson,** a PhD student with registration number **ED/SED/15/0004** who has been assigned to collect data at your institution.

Mr. Koomson is conducting a research on the topic: "**AN INVESTIGATION INTO THE DEVELOPMENT OF SCIENCE PROCESS SKILLS BY SENIOR HIGH SCHOOL CHEMISTRY STUDENTS**".

We humbly request that you grant him permission to collect the data and offer him any assistance relevant to the conduct of his research at your institution.

Kindly find attached the list of selected schools for your further action.

Counting on your usual support.

Thank you.

Yours faithfully,

Prof. Christian Anthony-Krueger
SUPERVISOR

APPENDIX M

FORMULAE PREDICTING STUDENTS' WASSCE GRADES

Knowing the percentage compositions of basic science process skills and integrated science process skills in the WASSSCE papers, proportions of students who are expected to score A – C and A – E grades are predicted using the formula below:

$$\text{Expected \% (A – C)} = \frac{(\%\ \text{B.S} \times 51.1) + (\%\ \text{I.S} \times 44.7)}{4825.6} \times 48.5$$

$$\text{Expected \% (A – E)} = \frac{(\%\ \text{B.S} \times 51.1) + (\%\ \text{I.S} \times 44.7)}{4825.6} \times 70.7$$

Where: (B.S = basic science process skills component of the paper; I.S = integrated science process skills of the paper).