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USING THE 5C's MODEL OF INSTRUCTION TO IMPROVE STUDENTS' CONCEPTUAL UNDERSTANDING IN HYBRIDISATION OF MOLECULES

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USING THE 5C's MODEL OF INSTRUCTION TO IMPROVE STUDENTS' CONCEPTUAL UNDERSTANDING IN HYBRIDISATION OF MOLECULES

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DECLARATION

Student's Declaration

I, Isaac Arhin, hereby declare with academic honesty that this work is the outcome of my research work carried out in the Department of Science Education, Faculty of Science Education under the supervision of Prof. Sam Arkoful towards the "Master of Philosophy Degree in Science Education" except for the references, which served as a source of information, which I fully acknowledged. The work has never been presented for another certificate, diploma or degree in this University or elsewhere. However, I am personally responsible for errors, omissions and shortcomings that may be found in the text.

NAME OF STUDENTS: ISAAC ARHIN

SIGNATURE: ………………………….……………..…

DATE: ……………………………………………………

Supervisor's Declaration

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

NAME OF SUPERVISOR: PROF. SAM ARKOFUL

SIGNATURE: ………………………….……………..…

DATE: ……………………………………………………

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DEDICATION

With love and affection, this work is dedicated to my family.

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ANCOVA	:	Analysis of Covariance
BP	:	Bonding Pair
CPD	:	Continuous Professional Development
CPT	:	Chemistry Performance Test
GSS	:	Ghana Statistical Services
ICT	:	Information and Communication Technology
IDTM	:	Institute of Development and Technology Management
LP	:	Lone Pair
MIT	:	Mfantsiman Institute of Technology
MLT	:	Multimedia Learning Theory
MOT	:	Molecular Orbital Theory
Nσ	:	Number of Sigma Bonds
PBL	:	Problem Based Learning
PI	:	Peer Instruction
PjBL	:	Project Based Learning
π-BOND	:	Pi Bond
POGIL	:	Process Oriented Guided Inquiry Learning
RIP	:	Researcher‟s Instructional Package
SLT	:	Social Learning Theory
SPSS	:	Statistical Package for Social Sciences
STEM	:	Science, Technology, Engineering, and Mathematics

σ-BOND	:	Sigma Bond
TEFLON	:	Tetrafluoroethylene
VBT	:	Valence Bond Theory
Ve	:	Number of Valence Electrons
VSEPR	:	Valence Shell Electron Pair Repulsion
VSM	:	Visuo-Spatial Models

ABSTRACT

The main objective of the study was to examine how senior high school students‟ level of understanding on hybridisation of molecules can be improved with the use of 5C‟s model of instruction. The action research design was adopted. The study targeted senior high schools in the Cape Coast Metropolis. The selected school is Ghana National Senior High School. The simple random sampling technique was used to sample the students on their readily availability to the study. A sample of 110 students was included to participate in the study. Their responses were sought with the help of a structured questionnaire. The results showed that there was low level of understanding among the students on the concept of hybridisation. Only 6.4% of the respondents had sound understanding of hybridisation. Majority were unable to indicate the types of hybridisations. Majority of the students had misconceptions on atomic orbitals and hybrid orbitals which were pre-requisite for understanding the concept of hybridisation. There was a significant increase in level of knowledge regarding hybridisation of molecules by 5C‟s model of teaching (p-value = < 2.635). The mean value increased from 19.15 (pre-test) to 24.82 (post-test) and the mean difference of 5C‟s model was 5.67. It was recommended that chemistry teachers in schools in the Cape Coast Metropolis needs to move away from a traditional teaching style that makes students passive learners. Therefore, it is important that teachers adequately plan lessons, which include multiple representation challenging activities that actively engage students as this will help avoid simple rote learning.

CHAPTER ONE

INTRODUCTION

1.0 Overview

The introductory chapter aims to provide an overall contextualisation of this study. This is firstly done by providing a brief background to the study to understand its context. Thereafter, the statement of the problem and rationale are discussed. The overarching research question is mentioned along with the research objectives. The significance of the study is explained to the reader after which a section is devoted to delimitation and organisation of the study.

1.1 Background to the Study

Chemistry has become one of the most important disciplines in the school curriculum; its importance in the general education has gained world-wide recognition. Ejidike and Oyelana (2015) asserted that the performance of students in science-based subjects like chemistry is closely related to their theoretical and practical knowledge while some are taught in isolation from the process of discovery or the conceptual applications. This however, depends solely on the subject at various classes and also on particular factors within and without the teaching and learning environment (Hume, Carson, Hodgen, & Glaser, 2011; Felder, Felder, & Diet, 2013).

Olaleye (2012) observed that there are number of factors that limit the effectiveness of the teaching of chemistry. These include a lack of qualified science teachers, a lack of laboratory equipment and instructional materials such as textbooks, models and audio-visual aids to demonstrate scientific principles. In addition, Olaleye (2012) indicated that students find the learning of chemical concepts difficult and boring hence; their performances in chemistry tend to be lower when compared to other subject areas. Teachers lack the laboratory facilities and models needed to make the abstract concepts of chemistry real and accessible for students and therefore need to find new ways of making classroom activities more engaging for students.

When the achievements of hybridisation are examined under the secondary education chemistry program, students are required to understand the hybrid orbitals and atomic orbitals and explain the formation of single, double and triple bonds (Sevgül, 2018). In 1931, Pauling introduced the hypothesis of hybridisation and gave an explanation for the four bonds being identical. According to the theory of hybridisation, carbon‟s s and three p orbitals lose their atomic properties and make bonds by creating four identical orbits with unique features (Sevgül, 2018). Hybridisation theory is a theory used to describe the bond structure of all single, double and triple bonds made by carbon and hetero atoms in the structure of organic molecules (Atasoy, 2018). Like many other topics in chemistry, the concepts of atomic orbital and hybridisation are also abstract, making them difficult to learn.

Students need to know atomic orbitals and chemical bonding to understand the hybridisation process. They are also expected to determine the hybridisation pattern of the central atoms of molecules with different geometries. However, in many studies (Şen & Yılmaz, 2013; Demirci, Yılmaz, & Şahin, 2016), it has been shown that students have difficulty in recognising chemical bonds. Çepni (2014), Bouayad, Kaddari, Lachkar, and Elechga (2014) argued that students in different countries also have difficulties in distinguishing chemical bonds from each other. The s, p and d atomic orbitals and hybrid orbitals, which are different mathematical mixtures of these orbits, need to be well known so that chemical bonds can be well explained, and more meaningful and effective learning can be achieved (Salah & Dumon, 2011).

The quality of education provided changes with changing attributes and abilities of teachers including their proficiency, hard work, dedication and enthusiasm (Mensah, 2016; Rahman, Jumani, Akhter, Chisthi, & Ajmal, 2011). Commenting on the role effective teachers play in achieving a nation‟s educational goals (Opfer and Pedder, 2011) revealed that for student learning to improve, there is need for a route for effective professional learning engagements for teachers whiles in the teaching profession. Thus, there should be a sporadic curricula intervention as well as resourced teachers and instructors who are willing and ready to deliver the content of education to the full. Usually, they do not see something wrong with the curriculum, the teaching methods, and the medium of instruction used in school.

Likewise, teachers often do not reflect on teaching and learning materials (TLM) and the communication styles used in the classroom (Gyasi, 2011; Kuyini, 2013; Kuyini & Abosi, 2011). Agbenyega and Deku (2011) argued that some learners do not benefit from teaching methodologies and materials used in the regular classroom. In addition to teaching multiple strategies and approaches to achieve learner centered classroom teaching, teacher educators are also charged with teachers with the experience, knowledge, and tools to engage in culturally responsive teaching (Sobel, Gutierrez, Zion, & Blanchett, 2011). Hence, the need to use the appropriate methods that can stimulate the interest of students towards learning of chemistry at all levels of our educational system to make chemistry realize its ultimate goals in the curriculum and in the national policy on education.

Teaching methods have become an important pathway that should not be undermined by chemistry teachers and should be applied appropriately in order to enhance learning outcomes of students.

According to Justi and Gilbert (2002), a complementary view comes from other researchers who suggest that models and understanding modelling can provide essential perspectives on the conceptual development of chemistry as well as the scope and limitations for all models. Justi and Gilbert (2002) advocate that students have opportunities to develop and test their own models. The current challenges for research and development in chemistry that Justi and Gilbert (2002) advocate are the issues regarding how teachers needs would be addressed including how teachers can effectively introduce modelling in instruction such that students really understand the nature of chemistry from a critical perspective.

Clearly, these researchers and others are concerned with the current status of chemistry instruction and their perspective is that the practice of teaching be guided by symbolic presentations. Similarly, understanding hybridisation of molecules is critical for learners of chemistry because this topic serves as the foundation for effective understanding of organic chemistry. It is therefore not surprising that these topics are characteristically found in the early sessions of the chemistry syllabus for Senior High Schools in Ghana.

Meanwhile, studies conducted by Ameyaw and Sarpong (2011) affirmed that, in the 21st century learning, it is necessary to allow learners to get wider scope of opportunity to explore their learning environment and make decisions on their own instead of being information receivers. It is upon this revelation that the study was conducted to investigate problems associated with teaching and learning of hybridization of molecules. It is also to find out if using 5C‟s model of instruction in learning of hybridisation of molecules can enhance instruction and learning of hybridization of molecules.

The 5C‟s Framework is founded on constructivist and collaborative learning theories where knowledge is constructed physically by active learning; symbolically by the creation of mental representations; socially by sharing understanding; and, theoretically by explaining things having incomplete understanding (Harney, Hogan, & Broome, 2012; Mingfei & Jie, 2010). According to Tom (2015), the implementation of the 5C‟s Framework was founded on accepted practices such as explaining concepts using multiple methods. Students set definite goals in terms of final results and a workable time schedule for learning in the beginning of the term with guidance from the teacher. Examples and problems are designed to give a more authentic and contextualised experience to the students.

1.2 Statement of the Problem

Many research studies have revealed that students have misconceptions about atomic orbitals and hybrid orbitals (Nakigoglu, 2003), have alternative conceptions concerning Molecular Hybridisation, Molecular Geometries and associated Bond Angles (Harrison & Treagust, 2000).

As an experienced chemistry teacher, I have also identified that students have misconceptions about atomic orbitals and hybrid orbitals as a result of students lack of conceptual understanding of hybridisation of molecules. The lack of conceptual understanding and misconceptions are believed to adversely affect students‟ performance in external examinations regulated by the West African Examinations Council (WAEC).

From the 2018 Chief Examiners‟ report, students were asked to briefly explain the significance of the letters x, y, and z as appeared in degenerate orbitals. Although some students were able to explain how carbon shows covalency of four equivalent bonds, they could not give a diagram of the shape of the orbitals formed. This indicates that students lack the conceptual understanding in hybridisation of molecules, hence the need to improve upon it. Observations from students" exercise books also showed that students could not give a diagram of the shape of the orbitals formed. Other students were also not able to determine the type of hybridisation that exist between compounds and molecules.

Several and detailed researches (Talanquer, 2011; Ameyaw & Sarpong, 2011; Essumang & Bentum, 2012) have been conducted to find out why chemistry concepts are difficult for students to understand. Some of the findings of such research works noted several factors that account for students" difficulty in understanding chemistry concepts as: learning impediments due to incorrect explanations to three-dimensional learning, missing or fragmented content knowledge; learners limited mental working space, a low visuospatial thinking ability, insufficient understanding for the role of models, and students" common-sense reasoning.

However, the use of 5C"s model has proven to be effective in improving students" conceptual knowledge (Kosheleva & Kreinovich, 2010; Tom, 2015; Katradis, Fox & Tian, 2017) and this can be useful in the learning of hybridisation of molecules among senior high school students. There are not many studies that examine how senior high school students" level of conceptual understanding of hybridisation of molecules can be improved with the use of 5C"s model of instruction. For this reason, in order to determine the extent of the achievements on hybridisation within the scope of the high school chemistry program, this study was aimed to overcome the deficiency in the field.

1.3 The Purpose of the Study

The purpose of the study is to examine how senior high school students‟ level of conceptual understanding on hybridisation of molecules can be improved with the use of 5C‟s model of instruction.

1.4 Objectives of the Study

The objectives of the study were to:

1. assess the level of students‟ conceptual understanding on hybridisation of molecules among senior high school students.
2. examine the level of student‟s conceptual understanding of senior high school students on atomic orbital and hybrid orbital.
3. determine the effectiveness of the use of 5C‟s model in improving students‟ conceptual understanding in hybridisation of molecules.

1.5 Research Questions

The study is guided by the following three research questions:

1. What is the level of students‟ conceptual understanding on hybridisation of molecules among senior high school students?
2. What is the level of students‟ conceptual understanding in atomic orbitals and hybrid orbitals?
3. How effective is the use of 5C‟s model in improving students‟ conceptual understanding in hybridisation of molecules?

Hypothesis

The following null hypothesis was tested in the study:

H_o: There is no significant difference in using the 5C‟s model of instruction in improving students‟ conceptual understanding in hybridisation of molecules.

1.6 Educational Significance of the Study

The primary importance of this project is to bring to light the usefulness and the possibilities of 5C"s model for effective teaching and learning of hybridisation of molecules. It brings out the benefits that the use of 5C"s model offer students and how to help teachers to effectively and efficiently teach hybridisation of molecules to inculcate creative thinking in their students. It can also boost the interest of teachers and students and foster the creative transfer of abilities of the students to other subjects. The study can also serve as reference material for further research into the development of other activities for instruction that may reflect ways and means students learn hybridisation of molecules.

1.7 Delimitation of the Study

This study was conducted in the Cape Coast Metropolis. The selected school was Ghana National Senior High School. Specifically, the study captured issues pertaining to students" conceptual understanding in hybridisation of molecules, atomic orbitals and hybrid orbitals among students in Ghana National Senior High School, as well as the effectiveness of the use of 5C"s model in improving students" conceptual understanding in hybridisation of molecules. This study adopted the action research.

1.8 Limitations of the Study

Since questionnaire played a major role in the study, the likelihood of respondents providing false information is high hence, affecting the reliability of the results. The population was limited to only Ghana National Senior High School for easy handling of the data and cross-examination of given information.

The researcher also assumed that students of the two selected schools had similar characteristics with students in other senior high schools who pursue chemistry as a course. This made it possible to generalise the findings of the study within the context of the targeted population.

1.9 Organisation of the Study

The study was organised into five chapters. Chapter one covered the background to the study, statement of the problem, purpose of the study, objectives of the study, research questions, significance of the study, delimitations of the study, limitations of the study, and organisation of the study. Chapter two of the study reviewed related literature to ascertain works that have been done in the chosen research area. It explained key concepts and draws out empirical evidence on the research objectives. Chapter three described the research methodology, and discuss the research design, sample and sampling procedure. Research instrument, data collection procedure, and data analysis procedure were also discussed in this chapter. Chapter four contained data presentation and discussions of the results in line with the research questions and existing literatures. Chapter five highlighted the summary of findings, and provide the conclusions and recommendation.

CHAPTER TWO

LITERATURE REVIEW

2.0 Overview

This chapter presented a review of related literature, which provides knowledge that has to do with the research topic. The chapter also included empirical evidence, which is relevant and appropriate to explain key variables, constructs or variables adopted to guide the study.

2.1 Theoretical Framework

According to Smith et al (2021). the theoretical framework can be seen as the basis of how "knowledge is constructed (metaphorically and literally); because for a research study it serves as the structure and support for the rationale for the study, the problem statement, the purpose, the significance, and the research questions. Azungah, (2018) provide the importance of a theoretical framework as it supports the scholar to present the theory guiding the research, and where it primarily considers the research problem. This study is academically grounded in three theories. The three are namely cognitivist, social learning theory and constructivism.

2.2 Cognitivist Theory

Jean Piaget provides a foundational basis for why we educate and provide an enhanced cognition to the learner occasioning the teacher‟s need for further training (Piaget, 1952). That sets the tone for understanding and engaging with the learning process. According to Phillips (1969), Piaget perceives the learner as one who is incessantly relating with the world around him or her by making clearer how to unpack the world around. The ambition of the child to solving problems engineered by the environment, the child takes steps to initiate set of actions to resolve the challenge. Cognitivism comes to the fore in that it brings the teacher reality of current relevance to learners and their community. Given that teachers of the two subjects are faced with the challenge of making problem solving skills available to learners in the simplest form, the practices of cognition need to be examined. The ultimate goal of education is enhanced learning outcome which is truly a function of cognition and meta cognition of facts in classroom learning process.

Instruction based on cognitive principles should be authentic and real. The teacher is expected to provide a rich classroom environment that fosters a child"s spontaneous exploration. Students are encouraged to explore instructional materials and to become active constructors of their own knowledge through experiences that encourage assimilation and accommodation. Yilmaz, (2011). Teaching is tailored to the needs, interests, and backgrounds of students (Yilmaz, (2011). The teacher is more concerned with constructing a meaningful context than directly teaching specific skills. From the cognitive perspective, because students learn by receiving, storing, and retrieving information, the teacher is urged to thoroughly analyse and consider the instructional materials, proper tasks, and relevant learner characteristics to help learners to effectively and efficiently process the information received McLeod, (2003).

Instructional materials should include demonstrations, illustrative examples, and constructive feedback so that students can have mental models to embody. Because information contained in instructional material is first processed by working memory, for schema acquisition to occur, instruction should be designed to reduce working memory load and to facilitate the changes in the long-term memory associated with schema acquisition (Sweller, 2013). In order to activate and utilise schema for learning, Barton states that the learner should be made aware of his background knowledge and exposed to strategies to bridge from pre-requisite skills to learning objectives (McLeod, 2003). The teacher is also expected to have a set of schemata for instructional activities in order to adroitly handle interactions between disparate goals and activities.

2.3 Social Learning Theory

Social learning theory (SLT) is increasingly cited as an essential component of sustainable natural resource management and the promotion of desirable behavioural change: (Gamira, 2022). This theory as proposed by Albert Bandura (1977) is based on the idea that we learn from our interactions with others in a social context. Separately, by observing the behaviours of others, people develop similar behaviours. After observing the behaviour of others, people assimilate and imitate that behaviour, especially if their observational experiences are positive ones or include rewards related to the observed behavior. According to Bandura (1977), imitation involves the actual reproduction of observed motor activities. It was observed that this theory integrates cognitive and social aspects of professional development and learning (Watson, 2013).

The fact is that, formation of individual knowledge is through observation and reflection (Bandura, 1977) and indeed according to philosophical positions of Social Learning Theory, it is a mental construction resulting from the connection of observed behaviours and engineering anticipated behaviours, without necessarily imitating other behaviours. Without doubt, this is the kind of engagement that continuous professional development (CPD) opportunities provide to teachers (Lortie, 2002). The SLT asserts that teachers" pedagogical knowledge in relation to their cognition of behaviours get to be acquired over time through repeated observations such as those opportunities that CPD presents. The foregoing provides a basis for theorising teachers" professional learning as a major element of teachers" continuous professional development.

2.4 Constructivism Theory

The third layer of the three theories that undergird this present study is constructivism, which relates to Vygotsky"s (1986) learning theory. The theory originally challenges the conventional targets of education by making one possessing the advance knowledge to allow the learner to construct knowledge themselves rather than simply receiving it from a more experienced teacher (Roblyer, Edwards, & Havriluk, 1997). Constructivism suggests applying teaching methods making the learner the active player and to encourage the learner to become cognitively engaged in developing understanding of the topic being taught. The more elaborated interpretations of constructivism not only seek to make students active thinkers, but to promote interaction and collaboration between them. The socio-constructivist framework suggests learning in interpersonal communication and social interaction as being essential for any effective learning (Eilks & Kapanadze, 2012). Socio-constructivism explains that effective learning requires a process that mainly functions through cultural and social mediation about content (Driver & Oldham, 1986; Lazarowitz & Hertz-Lazarowitz, 1998).

The theory of constructivism and how it is related to learning process due to its belief that people actively construct new knowledge as they interact with new environment. CPD programmes based on Vygotsky"s constructivism ideas engage the ideal classroom by scaffolding the two other theories namely cognitivist and SLT in order to systematise and perhaps institutionalise CPDs with the goal of increasing students leaning outcomes generally. Tippett, (2016) stressed that there are three lessons to learn about constructivism and students" conceptual development: first, the importance of listening to students and encouraging their active engagement; secondly, involving students in authentic tasks that challenge their existing ideas and thirdly, creating the environment that encourages individual learners to construct their own meaning within a social and cultural context which helps them remember and apply what they have learned to solve new problems in new learning contexts. The emphasis is on learners as active makers of meanings who construct their own knowledge in a social context that creates a connectedness with the world around them.

A central theme herein is the "Social Constructivist Learning Theory." The "Social Constructivist Learning Theory" implies that students learn better through active interactions with their peers rather than listening to lectures (Kristen, Malinda, Monica & Kendra, 2017). Social constructivist"s reason that through peer interactions, students are able to process new information in a way that"s understandable to them, therefore leading to higher order thinking. Science-based pedagogies that support the "Social Constructivist Learning Theory" are problem-based learning (PBL), process-oriented guided inquiry learning (POGIL), and project-based learning (PjBL) (Tseng, Chan, Lou & Chen, 2011; Barthlow & Watson, 2014; Vishnumolakala, Southam & Treagust, 2017).

From these theories, we know that science education should apply methods fostering activity in the students" contemplation with the content and also make science education a collaborative and cooperative practice. Instead of studying the mental content of individual minds, collaborative and cooperative learning focuses on the processes of interaction, participation, discourse, and negotiation. Cooperative learning leads to co-constructing knowledge and to building up collaborative knowledge where the group is able to attain a level of understanding that could not have been achieved through the mental processing of any one individual from within the group alone (Johnson & Johnson, 1999).

This is true for the learning of pure subject matter knowledge as well as the learning within contexts or learning via practical work. If all the different dimensions of making the student active – hands-on and minds-on – are used in science education, the classroom environment has high potential for effective learning, student motivation, and the development of skills beyond the rote learning of subject matter knowledge. More general educational skills will be promoted including inquiry skills, organising and structuring of projects, or team working abilities. In the end, higher cognitive achievement, better development of higher-level thinking skills, increased student self-confidence and satisfaction and better attitudes towards subject matter will be the result (Lazarowitz & Hertz-Lazarowitz, 1998).

2.5 The Five Cs of the 5C's Framework

The 5C"s model transforms the traditional lecture method with little or no interaction into multiple packs of interactive lessons (Tom, 2015). The Five Cs of the 5C"s framework encompasses:

1. Consistency – teacher is consistent in his/her teaching and learning practices. Formulas and relations to be used shall be applicable throughout the delivery.
2. Collaboration/Communication – there must be collaboration in problem solving and social construction of knowledge. Students are allowed to work in small

groups and are given group assignments to experiment their ideas. They are asked to communicate their ideas to their peers. Students are asked to do a presentation of the group work assigned to them. This would be followed by a question and answer (Q &A) session. Students then share something unique about what they have learnt and communicate their ideas to their peers. The small study groups would allow for guidance in creativity, exploration and growth in effective team work. Students grow in self-confidence.

3. Cognition – involves developing higher order thinking. Teacher asks questions that inspire critical thinking; students are given time bound activity that touches their brain and would make them work. Students are required to use critical thinking, team work and patience. Students would look proud in their faces after going through the activity.
4. Conception – in cognition teacher ensures that students understand the concept being taught through elaborations, assimilation and examples.
5. Creativity – the lesson is planned for students to create their own projects which are vastly different from one another. Students create solutions by applying the concepts learnt.

2.6 Chemistry Education

Teaching and learning are an encounter which demands voluntary contribution from all party involved to achieve the desired result in a school system. Attitudes, like academic achievement, are significant aftermaths of science education in high schools as research has confirmed that attitudes are linked with academic achievement and that attitudes predict behaviours (Cheung, 2009). To bring about conceptual change, it is equally important to promote students‟ awareness of the limitations of the instructional methods/models, as it is to provide the learners with accurate information (Ejidike, & Oyelana, 2015). Adesoji and Olatunbosun (2008) have investigated the effect of teacher-directed and self-directed problem-solving strategies on students‟ attitude toward chemistry and came to conclusion that if students were allowed to develop higher cognitive processes through problem solving strategies, either as teacher directed or self-directed, their attitudes toward chemistry might change positively. This means that success or failure depends to a great extent on the interest or attitude of the learners involved in learning models (Pyatt & Sims, 2012).

It therefore becomes imperative to estimate students/ learners‟ attitudes towards the instructional medium and instructional approach used for conceptual change to occur, and this approach should: be developmentally appropriate for students of all ages and ability levels; facilitate conceptual change, cognitive conflict and promote access for all students (Jaakkola, Nurmi & Veermans, 2011; Pyatt & Sims, 2012). Cheung (2009) reported that the correlation between high school students‟ achievement in chemistry and their attitudes toward chemistry ranged from 0.24 to 0.41. Helen (2010), in her report revealed that poor results in science subjects by girls may be attributed to gender polarisation and perception towards the subjects. "Girls are expected to be passive and subjective, and more interested in people than ideas". Francis and Greer (2006) concluded that boys showed a more positive attitude to learning chemistry than girls, but his research examined one particular year group while Barnes and Sydney (2006) used three items to measure student interest in chemistry by exploring sex differences in enrolment intentions expressed by 449 year 10 students from five high schools and concluded that males found chemistry more interesting than females (Cheung, 2009). Subsequently, the promotion of favourable attitudes towards science, scientists and learning science, as a component of science education, is a progressive matter of concern. Nevertheless, the concept of learners" attitude towards science has become vague, and often poorly enunciated (Osborne & Dillon, 2010).

Students" attitude toward science education could aroused through interest and motivation which gears towards the selection of the school courses and leads to the student careers (Aschbacher, Li & Roth, 2010; Harry, 2011). Thus, the attitude of students toward science and science education could be either positive or negative depending on the relative situation of the following: age and previous experiences, gender, teaching and learning method, lack of text book, laboratory activities, student"s motivations, ability and aptitude of student, home or family environment (Harry, 2011).

2.7 Pedagogical Methods Used in Senior High Chemistry Education

Senior High School chemistry teachers face a host of challenges as they are given the responsibility of deciding how they will deliver assigned curriculum. While chemistry is a part of our everyday lives, students have found that chemistry can be difficult to understand (Tarhan, Ayar, Urek & Acar, 2008). If a student is found to be weak in one area, additional support should be given to help that student strengthen their weak area so that they too can have an opportunity to realize their full potential. For teachers, fading time to provide additional support to help students overcome weak areas can be very difficult. Much like a complex equation, teachers must factor in numerous variables that will change every semester or year depending on student loads, student needs, grade levels, maturity, development, resources, as well as environmental factors outside the school (Kristen, Malinda, Monica & Kendra, 2017).

These intricate variables play a crucial role in developing a solution to this complex equation. Once the educator has determined those unknown variables, a decision can be made as to which pedagogical and technological methods to apply.

Active learning is facilitated through students‟ activities and by promoting student engagement. Achieving significant gains is possible, using active learning as opposed to didactic lectures enhances student learning continuously after missing fundamental concepts (Kristen, Malinda, Monica & Kendra, 2017). Science pedagogies discussed facilitate active learning and student engagement, through an inquiry-based problem approach. In order for students to achieve higher-order thinking, problems or questions should encompass several topics within the subject of chemistry. During the process of working through a problem, students identify problems, activate prior knowledge, and construct new knowledge in a comprehendible framework that is linked to prior knowledge learned (Oguz & Arabacioglu, 2011).

Chemistry students, in today‟s secondary education schools, need instruction that fosters active learning and student-peer engagement, while building 21st century workforce skills. Careful attention should be given to students presenting difficulty mastering chemistry concepts before assigning supplemental instructions. Chemistry instruction, best effective for student learning and building skills, incorporates social constructivist inquiry, based pedagogies with technology (Saavedram & Opfer, 2012). Differentiation between students, who are weak in one or more subject areas versus students struggling with a concept, should be identified. Chemistry teachers should provide students, who are weak in one or more subject areas, resources to build skills (Davis, Athey & Vandevender, 2015; Rhem, 2015). Students, who struggle with abstract concepts, greatly benefit from online simulations. Chemistry teachers can help students struggling in other subject areas to help strengthen weak skills.

Effective teaching of chemistry like other sciences demands consistency with the nature of scientific inquiry. Project 2061 (2010) observed that sound teaching usually starts with questions and phenomena that are interesting and familiar to learners as they try to find answers to such questions. The approach involves active engagement of learners and use of team approach to ensure frequent group activities in the classroom. It is usual to see scientists and engineers work mostly in groups instead isolated investigators. Learners in their groups come to common understandings and can always inform each other about procedures and meanings of the task at hand. By so doing, there is team responsibility, feedback and communication which become more realistic than the experiences of the usual individualistic textbook-homework-recitation approach. A purposeful and effective teaching of chemistry and science in general should reflect scientific values which culminate in curiosity, creativity, spirit of healthy questioning, promotion of aesthetic values and avoidance of dogmatism among the learners (Ochonogor, 2011).

2.8 Factors Influencing Effective Teaching of Chemistry

Effective science teaching is the gateway to attainment of scientific and technological greatness and this can be achieved via integrating theory with practical work. However, a greater deal of work has been done in an effort to identify problems that are inherent in the teaching of chemistry in secondary schools. These include physical classroom and laboratory: instructional arrangement and school management (Johnson, 2011). These factors influence the effective teaching of chemistry, which in turn plays a vital role in the lives of the students as it affects their performance. The physical classroom and laboratory indicated the presence of good ventilation, availability of good chalkboard, preparatory room, enough chairs and tables, charts and clean environment. The other factors include the presence of instructional materials in the laboratory such as apparatus and chemicals (Owoeye & Yara, 2011). Finally, the school management or organization is another vital factor that may be considered before anticipating a good result. The school management‟s responsibility now includes positioning of the school laboratory, school library, provision of essential services like water supply, light, food, vendors, counselor services and first aid services (Owoeye & Yara, 2011).

Owoeye and Yara (2011) observed that an important ingredient for the effective science teaching is an appropriate item; laboratory equipment and materials. A lot of concern has been shown about the inadequacy of science laboratory in schools. Laboratory has been given a central and distinct role in science education, and science educationalists have suggested that rich benefits in learning accumulate from using laboratory activities (Aina, 2012). To achieve the desired objective of effective teaching of chemistry in secondary schools, operational chemistry laboratory equipment has to be provided but it is disheartening to note that most of our schools do not have functional laboratories (Owoeye & Yara, 2011; Nwoye, 2012). Practical work allows students to have experience that are consistent with the goals of science literacy and have been used in many natural science disciplines to teach students of many age spans in different cultural and classroom contexts (Harry, 2011).

Learning environment does not only include the physical resources for learning, such as class arrangements, computers or laboratory experiment kits, also re-counts the teaching methods, learning styles and evaluation methods which in-turn facilitates learning environments research at all levels of education (Helding & Fraser, 2013). Learning environment assessments have been used in educational productivity research and in the evaluation of educational innovations (Chionh & Fraser, 2009). Abdullah (2009) blamed government for mass failure in chemistry and other science subjects due to the following reasons: little resources are made available without implementing effective government policies and servicing of education; inadequate trained staff for monitoring and evaluation of schools; collapsed infrastructure, lack of instructional materials; hostility of the environment, inadequate trained and experienced personnel, inadequate professional teachers‟ development and funding of the schools are inadequate. According to this group, the hindrance to the realization of education for all children is corruption, misplaced priorities, inequality and poor policy choices (Okoro, 2011).

A continuous teacher training is the keystone of improvement and transformation in schools, for personal growth and professional development (Okoro, 2011). The importance of in-service training and professional development of teacher has been given serious thought and effort. In-service training can be in the form of on-the-job training, workshops, post qualification courses, forma1 or informal, structured or unstructured (Mohammed, 2006). Okoro (2011) conducted a study on teacher education, school effectiveness, improvement and also stressed that teachers require professional knowledge and professional teaching skills, as well as a broad base of general knowledge in order to carry out instructional processes effectively. He further suggests that teachers should be both academically and professionally trained.

2.9 The 5C's Framework

The 5C"s model of instructional framework was developed with an understanding of the students" perspective of learning or more specifically the act of learning or how they do learn (Mota, Vaz de Carvalho & Reis, 2011). Engaging students from the three perspectives of affective, cognitive, and behavioural levels to build interest and deeper understanding is achieved through the 5C"s, that is, Consistency, Collaboration, Cognition, Conception, and Creativity (Wright, 2011; Mayer & Chandler, 2001). Students should be empowered with reflective lifelong learning skills to be successful in the highly dynamic field of Information and Communication Technology (ICT) where programming languages and tools constantly evolve. Also, students need to develop soft skills such as teamwork, communication skills, critical thinking, and creativity with the latter being one of the skills most sought after by industry (Welkener, 2013).

Traditional teacher-centric pedagogy is focused on the course content and transferring knowledge to the students whereas a learner-centric view is focused on assisting students to develop or build knowledge (Lister et al., 2007; Wright, 2011). Computer science pedagogy varies from developing skills in design and implementation focusing on the understanding of the machine aspects or real-world application aspects such as object-oriented design and development (Berglunda et al., 2009; Lister, Box, Morrison, Tenenberg & Westbrook, 2004). Therefore, a move from a teacher-centric to a learner-centered design is recommended (Smart, Witt & Scott, 2012; Wright, 2011).

The 5C"s framework is founded on cognitivist, constructivist and collaborative learning theories, Tom, (2015) and has knowledge to be constructed:

- physically by active learning;
- symbolically by the creation of mental representations;
- socially by sharing understanding; and,
- theoretically by explaining things having incomplete understanding.

Peer Instruction (PI) is well established by many studies especially in science, technology, engineering, and mathematics (STEM) subjects. It is based on small group discussions which positively contribute to student understanding (Porter, Bailey, Lee & Simon, 2013; Simon, Kohanfars, Lee, Tamayo & Cutts, 2010; Simon, Parris & Spacco, 2013). The PI framework was designed to assist students to progress through the seven levels of cognitive process and develop factual, conceptual, procedural, and metacognitive knowledge as per the revised Bloom‟s Taxonomy. Developing ideas or solutions require cognitive restructuring and assimilation (Quevedo-Torrero, 2009). Collaborative learning facilitates:

- cognitive constructivism where peer discussion leads to improved conceptual understanding;
- social construction of new knowledge by reflecting on the new material, cognitive restructuring, cognitive rehearsal, assimilation, correction of misconceptions, and searching for different perspectives of the newly introduced concepts through interaction and activity with others by asking questions, listening to explanations, and answering conflicting questions; and,
- teamwork and deeper understanding promoted by interaction among team members with varying levels of prior Tom, (2015). Collaboration also promotes cultivation of creativity and communication skills. A student who engages in a creative activity within the constraints of time and environmental elements and

working beyond the constraints of current norms/boundaries goes through a process transforming his/her knowledge into a product that is fulfilling for the student (Kleiman, 2008). Public oral presentations constitute an excellent opportunity for students to develop their communication skills, and stimulate reflection, critical thinking, and analysis (Requena-Carrion, Alonso-Atienza, Guerrero-Curieses & Rodriguez-Gonzalez, 2010).

2.10 Chemical Bonding and Molecular Structure

Matter is made up of one or different type of elements. Under normal conditions no other element exists as an independent atom in nature, except noble gases. However, a group of atoms is found to exist together as one species having characteristic properties. Such a group of atoms is called a molecule. Obviously, there must be some force which holds these constituent atoms together in the molecules. The attractive force which holds various constituents (atoms, ions, etc.) together in different chemical species is called a chemical bond. Since the formation of chemical compounds takes place as a result of combination of atoms of various elements in different ways, it raises many questions. Why do atoms combine? Why are only certain combinations possible? Why do some atoms combine while certain others do not? Why do molecules possess definite shapes? To answer such questions different theories and concepts have been put forward from time to time. These are Kössel-Lewis approach, Valence Shell Electron Pair Repulsion (VSEPR) Theory, Valence Bond (VB) Theory and Molecular Orbital (MO) Theory. The evolution of various theories of valence and the interpretation of the nature of chemical bonds have closely been related to the developments in the understanding of the structure of atom, the electronic configuration of elements and the periodic table. Every system tends to be more stable and bonding is nature‟s way of lowering the energy of the system to attain stability.

2.11 Kössel-Lewis Approach to Chemical Bonding

In order to explain the formation of chemical bond in terms of electrons, a number of attempts were made, but it was only in 1916 when Kössel and Lewis succeeded independently in giving a satisfactory explanation. They were the first to provide some logical explanation of valence which was based on the inertness of noble gases. Lewis pictured the atom in terms of a positively charged „Kernel‟ (the nucleus plus the inner electrons) and the outer shell that could accommodate a maximum of eight electrons. He further assumed that these eight electrons occupy the corners of a cube which surround the „Kernel‟. Thus, the single outer shell electron of sodium would occupy one corner of the cube, while in the case of a noble gas all the eight corners would be occupied.

This octet of electrons represents a particularly stable electronic arrangement. Lewis postulated that atoms achieve the stable octet when they are linked by chemical bonds. In the case of sodium and chlorine, this can happen by the transfer of an electron from sodium to chlorine thereby giving the Na^+ and Cl^- ions. In the case of other molecules like Cl_2, H_2, F_2, etc., the bond is formed by the sharing of a pair of electrons between the atoms. In the process each atom attains a stable outer octet of electrons.

2.12 Lewis Symbols

In the formation of a molecule, only the outer shell electrons take part in chemical combination and they are known as valence electrons. The inner shell electrons are well protected and are generally not involved in the combination process. G.N. Lewis, an American chemist introduced simple notations to represent valence electrons in an atom. These notations are called Lewis symbols. For example, the Lewis symbols for the elements of second period are as below:

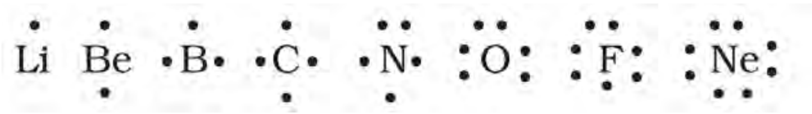

Figure 1: Lewis' Symbols for the Elements of Second Period

2.13 Significance of Lewis Symbols

The significance of Lewis symbols is that, the number of dots around the symbol represents the number of valence electrons. This number of valence electrons helps to calculate the common or group valence of the element. The group valence of the elements is generally either equal to the number of dots in Lewis symbols or 8 minus the number of dots or valence electrons.

Kössel, in relation to chemical bonding, drew attention to the following facts:

- In the periodic table, the highly electronegative halogens and the highly electropositive alkali metals are separated by the noble gases;
- The formation of a negative ion from a halogen atom and a positive ion from an alkali metal atom is associated with the gain and loss of an electron by the respective atoms;
- The negative and positive ions thus formed attain stable noble gas electronic configurations. The noble gases (with the exception of helium which has a duplet of electrons) have a particularly stable outer shell configuration of eight (octet) electrons, ns^2np^6.

- The negative and positive ions are stabilized by electrostatic attraction.

  For example, the formation of NaCl from sodium and chlorine, according to the above scheme, can be explained as:

Na	→	$Na^+ + e^-$
$[Ne]\ 3s^1$		[Ne]
$Cl + e^-$	→	Cl^-
$[Ne]\ 3s^2\ 3p^5$		$[Ne]\ 3s^2\ 3p^6$ or [Ar]
$Na^+ + Cl^-$	→	NaCl or Na^+Cl^-

Similarly, the formation of CaF_2 may be shown as:

Ca	→	$Ca^{2+} + 2e^-$
$[Ar]4s^2$		[Ar]
$F + e^-$	→	F^-
$[He]\ 2s^2\ 2p^5$		$[He]\ 2s^2\ 2p^6$ or [Ne]
$Ca^{2+} + 2F^-$	→	CaF_2 or $Ca^{2+}(F^-)_2$

The bond formed, as a result of the electrostatic attraction between the positive and negative ions was termed as the electrovalent bond. The electrovalence is thus equal to the number of unit charge(s) on the ion. Thus, calcium is assigned a positive electrovalence of two, while chlorine a negative electrovalence of one. Kössel"s postulations provide the basis for the modern concepts regarding ion-formation by electron transfer and the formation of ionic crystalline compounds. His views have proved to be of great value in the understanding and systematisation of the ionic compounds. At the same time, he did recognise the fact that a large number of compounds did not fit into these concepts.

2.14 Octet Rule

Kössel and Lewis in 1916 developed an important theory of chemical combination between atoms known as electronic theory of chemical bonding. According to this, atoms can combine either by transfer of valence electrons from one atom to another (gaining or losing) or by sharing of valence electrons in order to have an octet in their valence shells. This is known as octet rule.

2.15 Covalent Bond

Kohler Jr, (1974) refined the Lewis postulations by abandoning the idea of the stationary cubical arrangement of the octet, and by introducing the term covalent bond. The Lewis-Langmuir theory can be understood by considering the formation of the chlorine molecule, Cl_2. The Cl atom with electronic configuration, [Ne]$3s^2$ $3p^5$, is one electron short of the argon configuration. The formation of the Cl_2 molecule can be understood in terms of the sharing of a pair of electrons between the two chlorine atoms, each chlorine atom contributing one electron to the shared pair. In the process both chlorine atoms attain the outer shell octet of the nearest noble gas (i.e., argon).

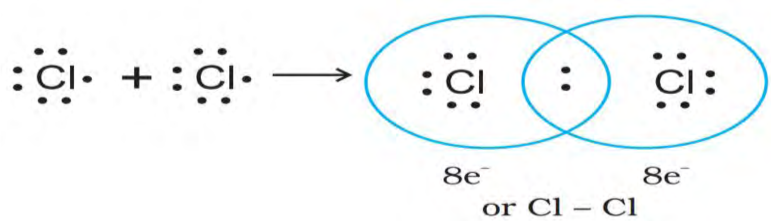

Figure 2: Covalent bond between two CI atoms

The dots represent electrons. Such structures are referred to as Lewis dot structures. The Lewis dot structures can be written for other molecules also, in which the combining atoms may be identical or different. The important conditions being that:

- Each bond is formed as a result of sharing of an electron pair between the atoms
- Each combining atom contributes at least one electron to the shared pair.

- The combining atoms attain the outer-shell noble gas configurations as a result of the sharing of electrons
- Thus, in water and carbon tetrachloride molecules, formation of covalent bonds can be represented as:

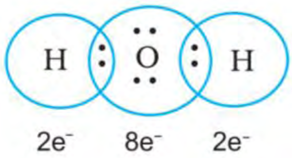

Figure 3: H atoms attain a duplet of electrons and O, the octet

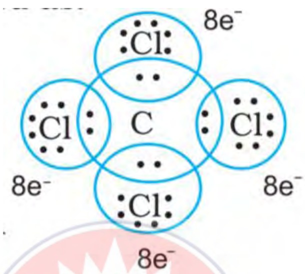

Figure 4: Each of the four CI atoms along with the C atom attains octet of electrons

Thus, when two atoms share one electron pair they are said to be joined by a single covalent bond. In many compounds we have multiple bonds between atoms. The formation of multiple bonds envisages sharing of more than one electron pair between two atoms. If two atoms share two pairs of electrons, the covalent bond between them is called a double bond. For example, in the carbon dioxide molecule, we have two double bonds between the carbon and oxygen atoms. Similarly, in ethene molecule the two carbon atoms are joined by a double bond.

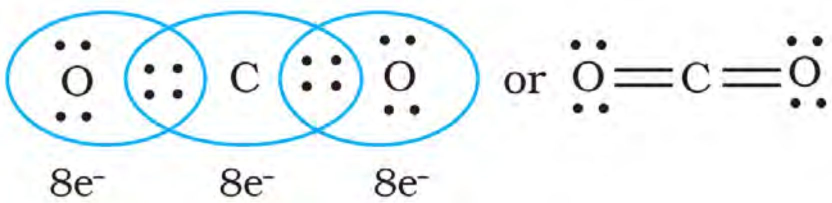

Figure 5: Double bonds in CO_2 molecule

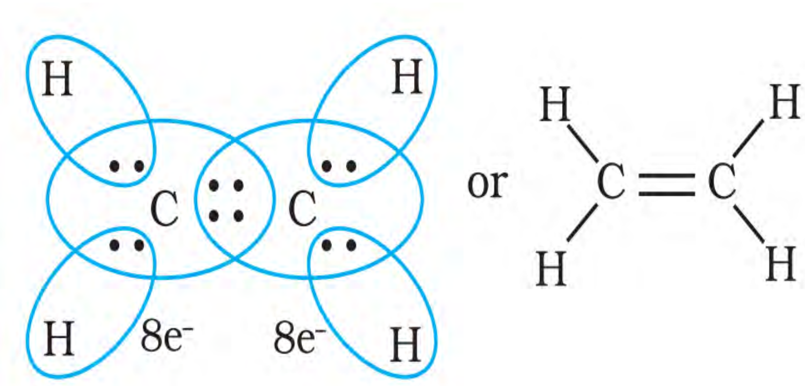

Figure 6: *C_2H_2* molecule

When combining atoms share three electron pairs as in the case of two nitrogen atoms in the N_2 molecules and the carbon atoms in the ethyne molecule, a triple bond is formed.

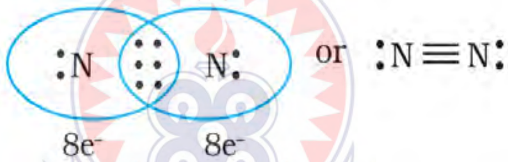

Figure 7: *N_2* molecule

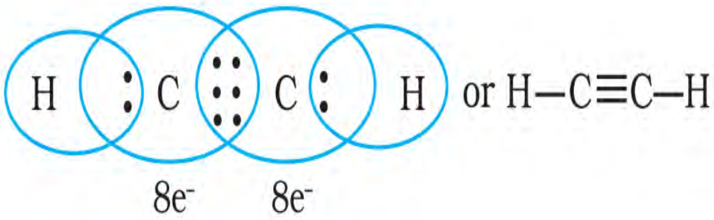

Figure 8: C_2H_2 molecule

2.16 Lewis Representation of Simple Molecules (The Lewis Structures)

The Lewis dot structures provide a picture of bonding in molecules and ions in terms of the shared pairs of electrons and the octet rule. While such a picture may not explain the bonding and behaviour of a molecule completely, it does help in understanding the formation and properties of a molecule to a large extent. Writing of Lewis dot structures of molecules is, therefore, very useful. The Lewis dot structures can be written by adopting the following steps:

- The total number of electrons required for writing the structures are obtained by adding the valence electrons of the combining atoms. For example, in the CH_4 molecule there are eight valence electrons available for bonding (4 from carbon and 4 from the four hydrogen atoms).
- For anions, each negative charge would mean addition of one electron. For cations, each positive charge would result in subtraction of one electron from the total
- number of valence electrons. For example, for the $CO^{2-}{}_3$ ion, the two negative charges indicate that there are two additional electrons than those provided by the neutral atoms. For $NH^+{}_4$ ion, one positive charge indicates the loss of one electron from the group of neutral atoms.
- Knowing the chemical symbols of the combining atoms and having knowledge of the skeletal structure of the compound makes it easy to distribute the total number of electrons as bonding shared pairs between the atoms in proportion to the total bonds.
- In general, the least electronegative atom occupies the central position in the molecule/ion. For example, in the NF_3 and $CO^{2-}{}_3$ nitrogen and carbon are the central atoms whereas fluorine and oxygen occupy the terminal positions.
- After accounting for the shared pairs of electrons for single bonds, the remaining electron pairs are either utilized for multiple bonding or remain as the lone pairs. The basic requirements being that each bonded atom gets an octet of electrons.

2.17 The Valence Shell Electron Pair Repulsion (VSEPR) Theory

As already explained, Lewis‟s concept is unable to explain the shapes of molecules. This theory provides a simple procedure to predict the shapes of covalent molecules. Sidgwick, & Powell, (1940) proposed a simple theory based on the repulsive interactions of the electron pairs in the valence shell of the atoms. It was further developed and redefined by Mingos, (2016).

The main postulates of VSEPR theory are as follows:

- The shape of a molecule depends upon the number of valence shell electron pairs (bonded or nonbonded) around the central atom.
- Pairs of electrons in the valence shell repel one another since their electron clouds are negatively charged.
- These pairs of electrons tend to occupy such positions in space that minimize repulsion and thus maximise distance between them.
- The valence shell is taken as a sphere with the electron pairs localising on the spherical surface at maximum distance from one another.
- A multiple bond is treated as if it is a single electron pair and the two or three electron pairs of a multiple bond are treated as a single super pair.
- Where two or more resonance structures can represent a molecule, the VSEPR model is applicable to any such structure.

The repulsive interaction of electron pairs decreases in the order:

Lone pair (lp) – Lone pair (lp) > Lone pair (lp) – Bond pair (bp) > Bond pair (bp) – Bond pair (bp)

Nyholm and Gillespie (2021) refined the VSEPR model by explaining the important difference between the lone pairs and bonding pairs of electrons. While the lone pairs are localised on the central atom, each bonded pair is shared between two atoms. As a result, the lone pair electrons in a molecule occupy more space as compared to the bonding pairs of electrons. This results in greater repulsion between lone pairs of electrons as compared to the lone pair - bond pair and bond pair - bond pair repulsions. These repulsion effects result in deviations from idealised shapes and alterations in bond angles in molecules. For the prediction of geometrical shapes of molecules with the help of VSEPR theory, it is convenient to divide molecules into two categories as (i) molecules in which the central atom has no lone pair and (ii) molecules in which the central atom has one or more lone pairs.

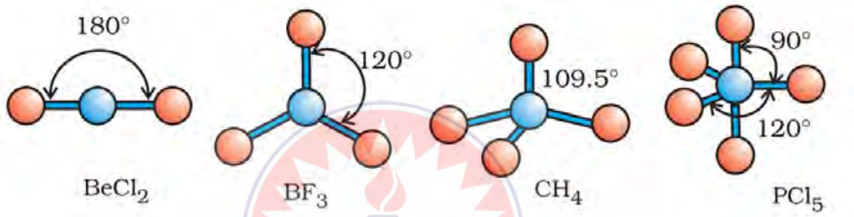

Figure 9: The shapes of molecules in which central atom has no lone pair

The VSEPR Theory is able to predict geometry of a large number of molecules, especially the compounds of *p*-block elements accurately. It is also quite successful in determining the geometry quite-accurately even when the energy difference between possible structures is very small. The theoretical basis of the VSEPR theory regarding the effects of electron pair repulsions on molecular shapes is not clear and continues to be a subject of doubt and discussion.

2.18 Valence Bond Theory

The Lewis approach helps in writing the structure of molecules but it fails to explain the formation of chemical bond. It also does not give any reason for the difference in bond dissociation enthalpies and bond lengths in molecules like H_2 (435.8 kJ mol^{-1}, 74 pm) and F_2 (155 kJ mol^{-1}, 144 pm), although in both the cases a single covalent bond is formed by the sharing of an electron pair between the respective atoms. It also gives no idea about the shapes of polyatomic molecules. Similarly, the VSEPR theory gives the geometry of simple molecules but theoretically, it does not explain them and also it has limited applications. To overcome these limitations the two important theories based on quantum mechanical principles are introduced. These are valence bond (VB) theory and molecular orbital (MO) theory.

Valence bond theory was introduced by Pauling, (1931) and developed further by Pauling and others. A discussion of the valence bond theory is based on the knowledge of atomic orbitals, electronic configurations of elements, the overlap criteria of atomic orbitals, the hybridization of atomic orbitals and the principles of variation and superposition. A rigorous treatment of the VB theory in terms of these aspects is beyond the scope of this work. Therefore, for the sake of convenience, valence bond theory has been discussed in terms of qualitative and non-mathematical treatment only. To start with, let us consider the formation of hydrogen molecule which is the simplest of all molecules.

Consider two hydrogen atoms A and B approaching each other having nuclei N_A and N_B and electrons present in them are represented by e_A and e_B. When the two atoms are at large distance from each other, there is no interaction between them. As these two atoms approach each other, new attractive and repulsive forces begin to operate.

Attractive forces arise between:

i. nucleus of one atom and its own electron that is $N_A - e_A$ and $N_B - e_B$.

ii. nucleus of one atom and electron of another atom i.e., $N_A - e_B$, $N_B - e_A$.

Similarly repulsive forces arise between

i. electrons of two atoms like $e_A - e_B$,

ii. nuclei of two atoms $N_A - N_B$.

Attractive forces tend to bring the two atoms close to each other whereas repulsive forces tend to push them apart. Experimentally it has been found that the magnitude of new attractive force is more than the new repulsive forces. As a result, two atoms approach each other and potential energy decreases. Ultimately a stage is reached where the net force of attraction balances the force of repulsion and system acquires minimum energy. At this stage two hydrogen atoms are said to be bonded together to form a stable molecule having the bond length of 74 pm. Since the energy gets released when the bond is formed between two hydrogen atoms, the hydrogen molecule is more stable than that of isolated hydrogen atoms. The energy so released is called as bond enthalpy. Conversely, 435.8 kJ of energy is required to dissociate one mole of H_2 molecule.

$$H_2(g) + 435.8 \text{ kJ mol}^{-1} \rightarrow H(g) + H(g)$$

2.19 Orbital Overlap Concept

In the formation of hydrogen molecule, there is a minimum energy state when two hydrogen atoms are so near that their atomic orbitals undergo partial interpenetration. This partial merging of atomic orbitals is called overlapping of atomic orbitals which results in the pairing of electrons. The extent of overlap decides the strength of a covalent bond. In general, greater the overlap the stronger is the bond formed between two atoms. Therefore, according to orbital overlap concept, the formation of a covalent bond between two atoms results by pairing of electrons present in the valence shell having opposite spins.

2.20 Molecular Orbital Theory

Molecular orbital (MO) theory was developed by Hund and Mulliken in 1932. The salient features of this theory are:

i. The electrons in a molecule are present in the various molecular orbitals as the electrons of atoms are present in the various atomic orbitals
ii. The atomic orbitals of comparable energies and proper symmetry combine to form molecular orbitals
iii. While an electron in an atomic orbital is influenced by one nucleus, in a molecular orbital it is influenced by two or more nuclei depending upon the number of atoms in the molecule. Thus, an atomic orbital is monocentric while a molecular orbital is polycentric.
iv. The number of molecular orbitals formed is equal to the number of combining atomic orbitals. When two atomic orbitals combine, two molecular orbitals are formed. One is known as bonding molecular orbital while the other is called antibonding molecular orbital
v. The bonding molecular orbitals has lower energy and hence greater stability than the corresponding antibonding molecular orbital
vi. Just as the electron probability distribution around a nucleus in an atom is given by an atomic orbital, the electron probability distribution around a group of nuclei in a molecule is given by a molecular orbital
vii. The molecular orbitals like atomic orbitals are filled in accordance with the Aufbau principle obeying the Pauli"s exclusion principle and the Hund"s rule.

2.21 Hybridisation

Hybridization is a theoretical concept which was introduced by Linus Pauling. He described it as the redistribution of the energy of orbitals of individual atoms to give new orbitals of equivalent energy and named the process as hybridisation (Pauling, 1940). Jain (2014) defined hybridisation as the intermixing of dissimilar orbitals of the same atom but having slightly different energies to form same number of hybrid orbitals of equal energies and identical shapes. The concept of hybridisation is mainly used to predict the geometry of certain covalent bonded polyatomic molecules and ions. In this process, the new orbitals come into existence and named as the hybrid orbitals. Using hybridisation process helps to explain the following observed facts; (i) tetravalency of carbon, that all C-H bond lengths are equal in CH_4 molecule as well all H-C-H bond angles are equal i.e., 109.5^o (ii) geometry of certain covalent bonded molecules and ions (iii) existence and non-existence of certain molecules in nature (iv) relative bond strength of sigma molecular orbital/sigma bonds (σ-bonds) and pi molecular orbital/pi- bonds (π-bonds) bonds.

2.22 Characteristics of Hybridisation Process

1. Hybridisation takes place only in orbitals belonging to the same atom or ion.
2. All the hybridised orbitals obtained after mixing process have the same energy and shape but differ in their orientation.
3. Hybridisation never takes place in an isolated atom or ion but it occurs only when an atom or ion is undergoing to form covalent bonds with two or more atoms.
4. Orbitals of almost similar energies undergo hybridisation. Hence, a 2s orbital cannot be hybridised with 3s orbital as the energy difference is more. Both half -

filled or fully- filled or vacant orbitals (in complexes) can involve in hybridisation process.

5. Hybridised orbitals provide more efficient overlapping than overlapping by pure s, p and d-orbitals due to fixed orientation or more directional nature of hybridised orbitals. Hence, hybridisation is also known as „Principle of maximum overlapping‟.
6. Generally, „d‟ orbitals do not take part in hybridisation process due to their very large size or high energy as compared to that of „s‟ and „p‟ orbitals but mixing of „d‟ orbitals takes place in the presence of more electronegative atom than the central atom due to contraction in the size of „d‟ orbitals.
7. All the hybridised orbitals tend to be placed themselves as far apart from each other as possible to minimize the repulsive forces.
8. After hybridisation process, we get the same number of hybridised orbitals as are participating in the mixing process according to the law of conservation of orbitals.
9. On the basis of above characteristics, the following facts are formulated for a clear understanding and prediction of hybridised state of an atom in a polyatomic molecule or ion.

1. Generally, there is no hybridisation process without involvement of s-orbital because s-orbital provides a base or platform for mixing of p and d orbitals.
2. π-bonds are formed by lateral overlapping of pure p-orbitals or p and d-orbitals or d and d-orbitals of bonded atoms.
3. σ bonds are generally formed by axial overlapping of hybridised orbitals in a polyatomic molecule or ion.

4. Lone pairs on central atom of a molecule are generally considered to be present in hybridised orbitals provided if they are not involved in pπ-pπ, pπ-dπ bonding or in resonance.

2.23 Types of Hybridisation

Based on the type of orbitals involved in mixing, the hybridisation can be classified as sp, sp^2, sp^3, sp^3d or sp^3d^2.

sp Hybridisation

The sp hybridisation is observed when one s- and one p-orbital are mixed to form two sp – hybrid orbitals, having a linear structure with bond angle 180 degrees. For example, in the formation of $BeCl_2$, first Beryllium (Be) atom comes in excited state $2s^1 2p^1$, then hybridised to form two sp – hybrid orbitals. These hybrid orbitals overlap with the three p-orbitals of two chlorine atoms to form $BeCl_2$ as shown in Figure 10.

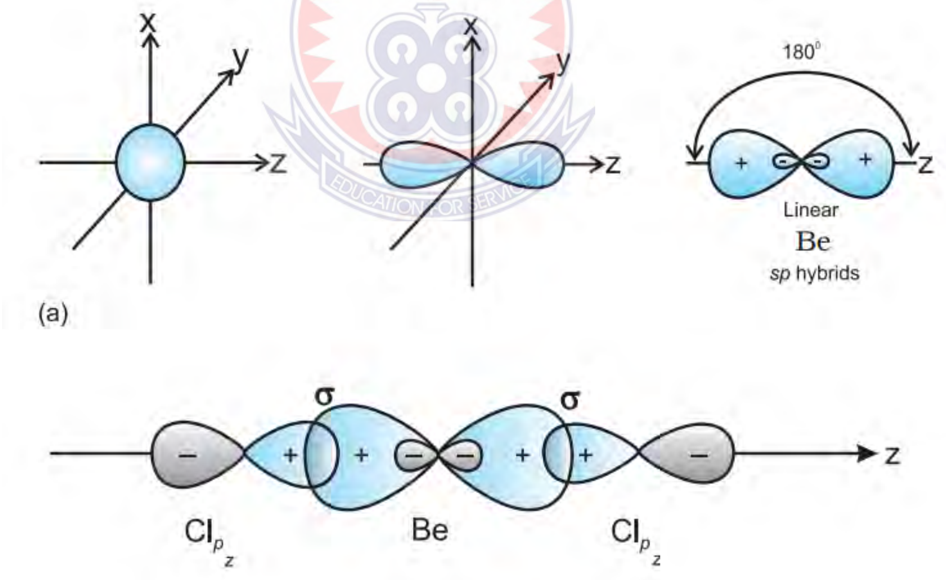

Figure 10: (a) Formation of sp hybrids from s and p orbitals (b) Formation of the linear $BeCI_2$ molecule

sp² Hybridisation

In such hybridisation one s- and two p-orbitals of the same shell of an atom are mixed to form three sp^2– hybrid orbitals, having a planar triangular structure with bond angle 120 degrees. The new orbitals formed are also called trigonal hybridisation. All the three hybrid orbitals remain in one plane and make an angle of 120° with one another. Each of the hybrid orbitals formed has 33.33% s character and 66.66% „p" character. The molecules in which the central atom is linked to 3 atoms and is sp^2 hybridised have a triangular planar shape. This is exemplified in Figure 11.

Examples of sp^2 Hybridisation:

- All the compounds of Boron i.e., BF_3, BH_3
- All the compounds of carbon containing a carbon-carbon double bond, Ethylene (C_2H_4)

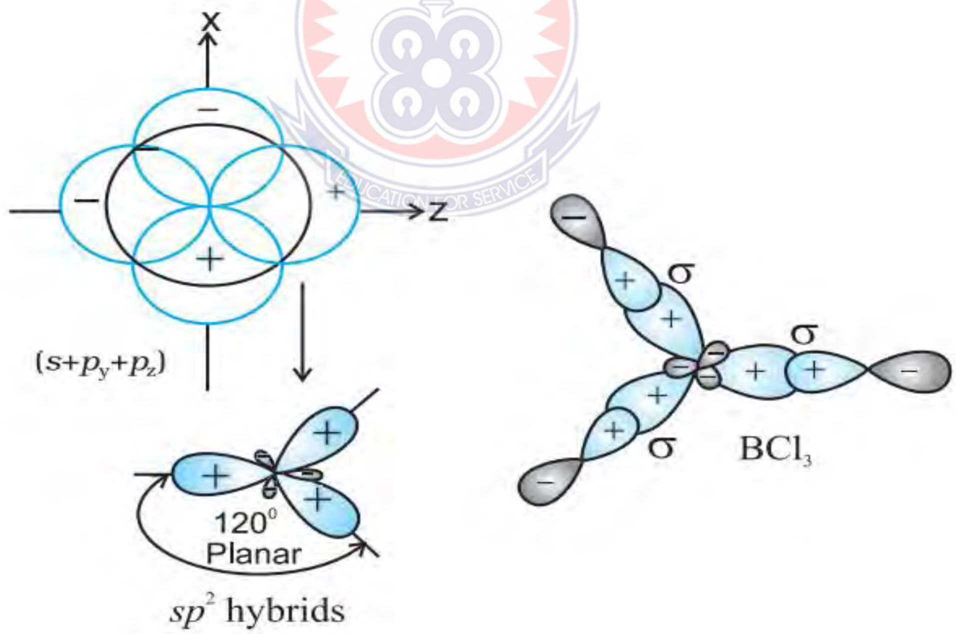

Figure 11: Formation of sp^2 hybrids and the BCl_3 molecule

sp³ Hybridisation

In such hybridization one s- and three p-orbitals are mixed to form four sp^3 – hybrid orbitals having a tetrahedral structure with bond angle of 109° 28". These are directed towards the four corners of a regular tetrahedron and make an angle of 109°28'' with one another, that is, 109.5°. Each sp^3 hybrid orbital has 25% s character and 75% p character. Example of sp^3 hybridisation: ethane (C_2H_6), methane in Figure 12.

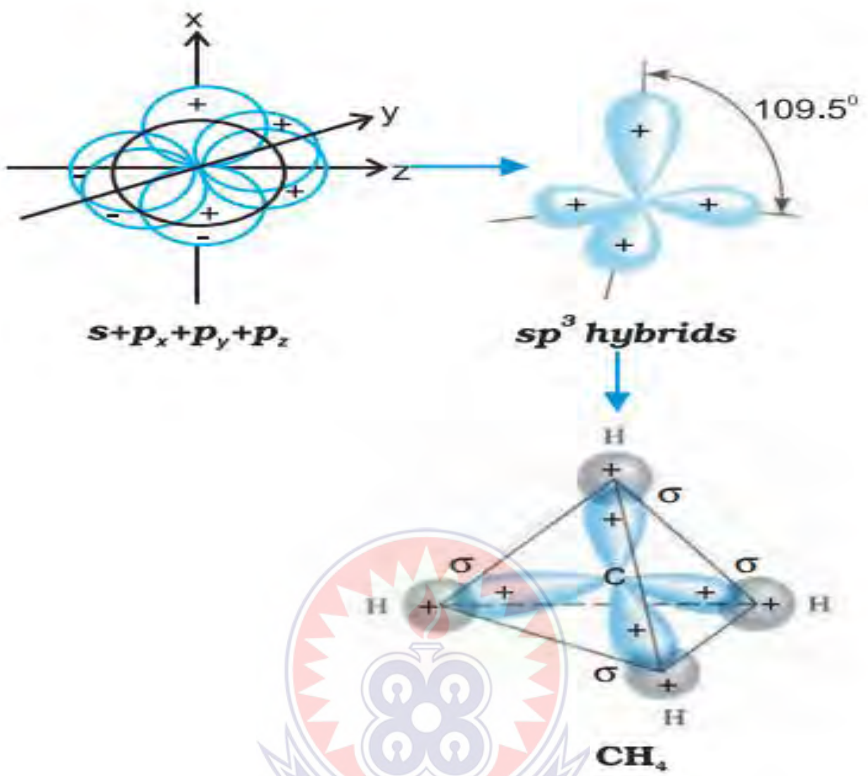

Figure 12: Formation of sp^3 hybrids by the combination of s, p_x, p_y, and p_z atomic orbitals of carbon and the formation of CH_4 molecule

sp^3d Hybridisation

The sp^3d hybridisation involves the mixing of 3p orbitals and 1d orbital to form 5 sp^3d hybridised orbitals of equal energy. They have trigonal bipyramidal geometry. The mixture of s, p and d orbital forms trigonal bipyramidal symmetry. Three hybrid orbitals lie in the horizontal plane inclined at an angle of 120° to each other known as the equatorial orbitals. The remaining two orbitals lie in the vertical plane at 90 degrees plane of the equatorial orbitals known as axial orbitals.

Example: Hybridisation in Phosphorus pentachloride (PCl_5) in Figure 13.

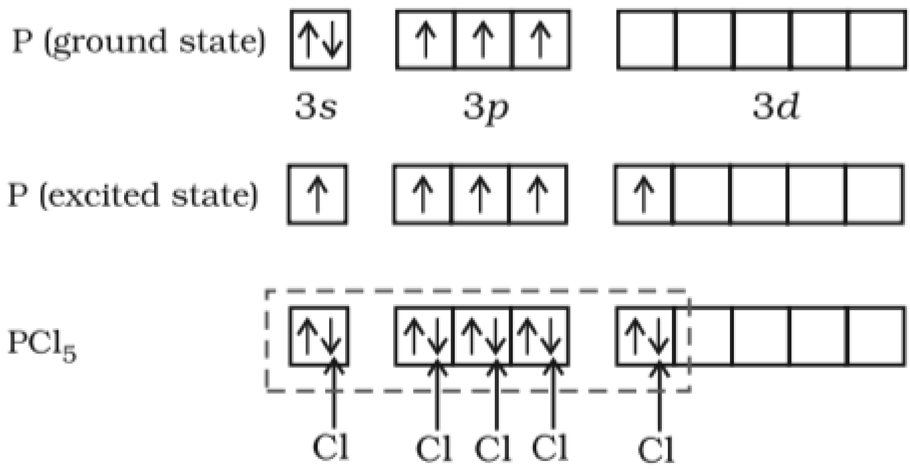

Figure 13: Formation of sp^3d hybrids orbitals filled by electron pairs donated by five Cl atoms

sp^3d^2 Hybridisation

The sp^3d^2 hybridisation has 1s, 3p and 2d orbitals, that undergo intermixing to form 6 identical sp^3d^2 hybrid orbitals. These 6 orbitals are directed towards the corners of an octahedron. They are inclined at an angle of 90 degrees to one another. In SF_6 the central sulphur atom has the ground state outer electronic configuration $3s^23p^4$. In the excited state the available six orbitals i.e., one s, three p and two d are singly occupied by electrons. These orbitals hybridise to form the six new sp^3d^2 hybrid orbitals, which are projected towards the six corners of a regular octahedron in SF_6. These six sp^3d^2 hybrid orbitals overlap with singly occupied orbitals of fluorine atoms to form six S-F sigma bonds as represented in Figure 14.

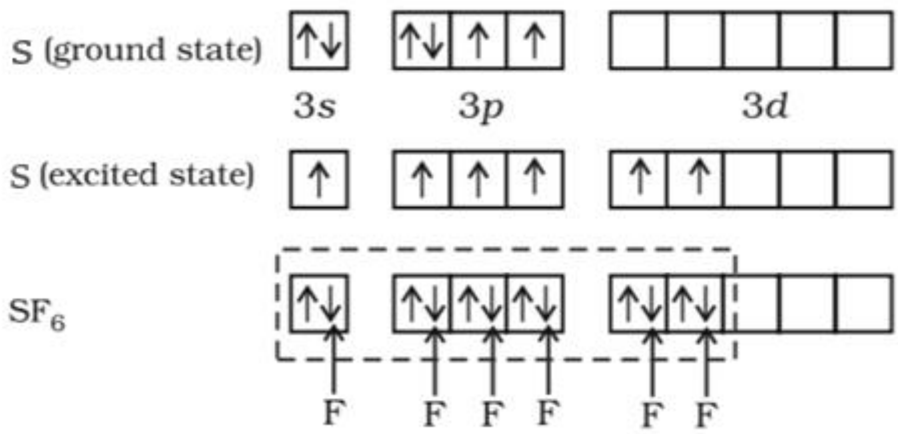

Figure 14: Formation of sp^3d^2 hybrids orbitals

2.24 How to Determine Type of Hybridisation

In order to figure out the hybridised state of an atom, fist we need to know the electronic structure of the molecule or ion then on the basis of electronic structure, we can easily predict the hybridised state of concerned atom. The structure of any molecule can be predicted on the basis of hybridisation which in turn can be known by the following general formulation,

$H = N\sigma + LP$

Where H= Number of orbitals involved in hybridisation including the s-orbital viz. 2, 3, 4, 5, 6 and 7, hence nature of hybridisation will be sp, sp^2, sp^3, $sp3^d$, sp^3d^2, sp^3d^3 respectively.

$N\sigma$ = Number of sigma bonds (σ- bonds) formed around each concerned atom,

LP = number of lone pairs present on concerned atom excluding lone pair involved in pπ-pπ, pπ-dπ bonding or in resonance.

All single (-) bonds are σ- bonds, in a double bond (=) there is one σ-bond and one pi-bond. In a triple bond there is one sigma bond (σ - bond) and two pi bonds (π -

bonds). In addition to these each lone pair (LP) and coordinate bond can be treated as one sigma bond subsequently. For example, in;

(a). NH_3: the central atom "N" is surrounded by three N-H single bonds, that is, three sigma bonds (σ) and one lone pair (LP), that is one additional sigma bond (σ). So, in NH_3 there is a total of four sigma bonds (σ), that is, three bonding pairs (BP) + one lone pair (LP) around the concerned atom "N". Therefore, in this case the number of orbitals present in this type of hybridisation is 4. Hence, the hybridization state of "N" in NH_3 = sp^3.

(b). H_2O: central atom "O" is surrounded by two O-H single bonds, that is, two sigma bonds (σ) and two lone pairs, that is two additional σ bonds. So, altogether in H_2O there are four σ- bonds and (two bond pairs + two lone pairs) around concerned atom "O". So, the hybridisation state of "O" in H_2O = sp^3.

(c). In I-Cl: I and Cl both have 4 σ- bonds and 3LPs, so, in this case power of the hybridisation state of both "I" and "Cl" = 4, that is, hybridisation state of "I" and "Cl" both are sp^3.

(d). In $CH_2 = CH_2$: each carbon atom is attached with 2C-H single bonds (2 σ-bonds) and one C = C bond (1 σ- bond), so, altogether there are 3 sigma bonds. So, in this case, power of the hybridisation state of both "C" = 3, that is, hybridisation states of both C"s are sp^2.

However, the drawback of this formulation is that first, one has to draw the electronic structure of the molecule which is a time-consuming process.

There is another formula which does not require the structure of the molecular ion and is less time consuming.

$H = \frac{1}{2}(V + M - C + A)$

Where H = Number of orbitals involved in hybridisation viz. 2, 3, 4, 5, 6 and 7, hence nature of hybridization will be sp, sp^2, sp^3, $sp3^d$, sp^3d^2, sp^3d^3 respectively.

V = Number of electrons in valence shell of the central atom;

M = Number of monovalent atoms

C = Charge on cation,

A = Charge on anion

This formular cannot predict the hybridised state of that central atom which is bonded with multivalent atoms like P_4, P_2O_5, P_4O_{10} and so many other similar molecules and ions. Another method is formulated which can be applied for a large number of molecules and ions without knowing their structure and one is able to predict the hybridised state of an atom in a very short time.

$H = ½ (Ve + M – C + A)$

Where H = number of orbitals involved in hybridisation viz. 2, 3, 4, 5, 6, and 7, hence nature of hybridisation will be sp, sp^2, sp^3, sp^3d, sp^3d^2, sp^3d^3 respectively.

Ve = Number of valence electrons of concerned atoms.

M = Number of other atoms excluding concerned and C, O, S (carbon, oxygen and sulphur atoms)

C = Charge on cation

A = Charge on anion

2.25 Students' Academic Performance

Academic performance of students especially is not only a pointer to the effectiveness or otherwise of schools but a major determinant of the future of youths in particular and the nation in general. Academic performance plays an important role in child development because academic skills, especially in reading and mathematics, affect many outcomes, including educational attainment, performance and income at work, physical and mental health, and longevity (Calvin et al., 2017). Academic performance was once thought to be the most important outcome of formal educational experiences and while there is little doubt as to the vital role such performances play in student life and later, researchers and policy makers are ever increasingly turning to social and emotional factors, as well as the relationships among them, as indicators of student well-being and psychological development (Chernyshenko, Kankaraš, & Drasgow, 2018; Moore, 2019). Academic performance is integrated also into the work of Eakman, Kinney, Schierl, & Henry, (2019), where the focus is on the complexities of the emotional and social lives of returned veterans and service personnel. Academic performance plays a role in the studies by Colmar, Liem, Connor and Martin (2019) and Martinez, Youssef-Morgan, Chambel and Marques-Pinto (2019).

According to Lopez et al. (2020), academic performance is the product of a set of psychological, social, and economic factors that lead to the proper development of students. Performance is not a single construct but rather subsumes a variety of different constructs like motivational beliefs, task values, goals, and performance motives (Wigfield et al., 2016). Performance motivation energizes and directs behaviour toward performance and therefore is known to be an import ant determinant of academic success (Wigfield et al., 2016). Several studies have been conducted in the last two decades that have analyzed the variables associated with academic success or failure in higher education (Gilar-Corb et al. 2020).

According to Schneider and Preckel (2017), the variables that explain academic performance are related to instructional factors such as social interaction, evaluation and feedback, clear information, extracurricular training programs, and so on, and also variables related to the student, such as intelligence, previous academic performance, motivation, strategies, and so on. Lack of prior academic preparation and economic and financial difficulties have been identified as potential causes of failure in the higher education system (Orozco et al., 2017; Vásquez-Martínez & Rodríguez-Pérez, 2020). According to Skaalvik (2018), previous academic records have been positively associated with mastery and performance-approach goals and have been negatively associated with performance-avoidance goals and academic anxiety.

2.26 Empirical Review

This section of the current study reviews related studies on level of conceptual understanding on hybridisation of molecules among senior high school students, and effectiveness of the use of 5C"s model in improving students" learning of understanding on hybridisation of molecules.

2.27 Level of Understanding on Hybridisation of Molecules among Students

Sevgül (2018) examined achievement levels of acquisitions in hybridisation among senior high school students. In this study with high school students, a descriptive scanning model, one of the qualitative research methods, was used to determine the extent to which the achievements of the hybridisation occurred. The study was conducted with 12th grade students studying in a public high school in Bursa in 2017-2018 academic year. According to the findings obtained from the research, it was determined that most of the high school students had difficulty in explaining the formation of single, double and triple bonds using atomic and hybrid orbital knowledge and expressing it verbally and schematically. It has also been found that students have problems in identifying the hybridisation type which the central atom in the given organic compound undergoes. For this reason, it was concluded that it is important to explain hybrids in detail at a high school level, taking advantage of teaching techniques and materials, paying attention to visuality during teaching and exploiting three-dimensional models.

Hanson, Sam and Antwi (2012) conducted a study to determine the misconceptions held by prospective teachers about atomic orbitals and hybridisation. A total of 88 undergraduate students were used in the study in the University of Education, Winneba, Ghana. The participants responded to multiple choice and constructed response questions on hybridisation at the start of the research. They answered the same set of questions at the end of a three-week treatment period. The responses were analyzed and response categories established on their misconceptions. The post-test was to assess their gain in conception at the end of the treatment period. Results indicated that pre-service teachers had gross misconceptions about atomic orbitals and hybridisation. Suggestions have been made for more effective teaching approaches to ensure better understanding of the concept.

Çil and Uğraş (2015) studied how Science Teaching undergraduate students comprehend "hybridisation". One hundred and seventy-six (176) students, 78 of whom are male and 98 of whom are female, participated in the study. A semi-structured questionnaire form was used in the study as data collection tool. As a result of analysis of data, it was determined that students describe hybridisation in 5 different categories and 4 different ways. According to these categories:

"1) Hybridisation is a kind of covalent bond, 2) an electronic transition between bonds, 3) an electronic transition between orbitals, 4) the mixing of atomic orbitals to form new orbitals suitable for bonding 5) a case observed as a result of interaction between particles. Among the categories, the one "a mixing of atomic orbitals to form new orbitals suitable for bonding" category was at the top of the list with 69 metaphors.

Farheen, and Lewis, (2021), studied the impact of representations chemical bonding on students‟ predictions of chemical properties. In this exploratory study, 1086 students in second semester general chemistry were randomly assigned to one of four representations showing bonding of sulfur dioxide: chemical formula, Lewis‟s dot structure, an image of a ball and stick model, or an image of a space filling model. Students were asked to predict chemical properties of sulfur dioxide: relative bond length, molecular polarity, and the strongest intermolecular force with a water molecule. Using the lens of Multimedia Learning Theory (MLT) on Learning with Text and Visual Representations, analyses of students‟ prediction of chemical properties and the features cited when making predictions was conducted. Effect sizes were used to describe variations among representations in terms of how students predicted bond length, polarity and intermolecular forces. Meaningful differences were found across representations in students‟ ability to correctly predict relative bond length and molecular polarity. Upon further testing, these hypotheses can inform instructors as to how to introduce representations and in the decision-making process of which representations to use to convey or assess a specific chemical property.

Claesen, Valkenborg, and Burzykowski, (2020), proposed a method for the prediction of S-atoms based on the aggregated isotope distribution. The Mahalanobis distance is used as dissimilarity measure to compare mass and intensity-based features from the observed and theoretical isotope distributions. The relative abundance of the second and the third aggregated isotopic variants (as compared to the monoisotopic one) and the mass difference between the second and third aggregated isotopic variants are the most important features to predict the number of S-atoms. It was concluded that the mass and intensity accuracies of the observed aggregated isotopic variants are insufficient to accurately predict the number of atoms. However, using a limited set of predictions for a peptide, rather than predicting a single number of S-atoms, has a reasonably high prediction accuracy.

2.28 Effectiveness of the Use of 5C's Model in Improving Students' Level of Understanding on Hybridisation of Molecules

Sarpong (2015) investigated the impact of using Visuo-Spatial Models (VSM) in teaching molecular geometry and hybridisation geometry with associate bond angles on college student"s performance at St. Joseph College of Education, Bechem. In the study, two cohorts labelled as experimental and control groups were used. The experimental group received instructions using the visuo-spatial approach of teaching. The control group on the other hand, was taught using the conventional approach of teaching. The study showed that students face difficulties to comprehend molecular and hybridisation geometries when presented to them in theoretical manner. It was found that conventional teaching approach makes concepts difficult for students to comprehend. Visuo-spatial model enhances student"s academic performance and argumentative skills far better than the conventional teaching approach. The research revealed that when students are taught through manipulations of VSM, it builds their visuo-spatial thinking (thinking through imaginations), develops their creative thinking skills, creates competition in learning among students, develops speaking and presentation skills of students, enhances their argumentative skills of students, and also prepares them to become tolerant towards others" views.

Tom (2015) examined the 5C"s Framework – Consistency, Collaboration, Cognition, Conception, and Creativity – that integrates constructivist and collaborative learning theories in a student-centered teaching pedagogy. This framework was found to be effective in postgraduate courses in introductory programming over three consecutive terms. Mfantsiman Institute of Technology (MIT) students who participated in this study belonged to three categories, those having a Bachelor"s degree in either: Computing, Engineering/Science, or Arts/Commerce. A total of 105 students participated in the testing and evaluation of this framework. Analysis conducted using survey and interviews indicates that the use of the 5C"s Framework reduced negative emotional issues, motivated students to become active learners, and improved the overall performance. Use of this framework transforms the learning to an enriching and enjoyable experience, developing a deeper understanding with improved cognitive skills, and development of soft skills such as team work, communication, and oral presentation. The 5C"s Framework may thus be seen to provide a model for student-centered teaching pedagogy which helps to minimize complexities for diverse student cohorts.

Tabinas (2019) carried out a study to examine teaching styles and instructional flows in chemistry courses, a pattern for a 5-step, 5-cycle teaching model. Specifically, the study aimed to identify the teaching styles the teachers used in the actual delivery of the chemistry lessons. Thus, this is a descriptive study on the teaching style employed and learning styles catered to in the actual teaching of a general chemistry course. In the process, instructional flows were described leading to a new teaching model, the

Five-Step, Five-Cycle Teaching model. This new teaching model is hoped to guide teachers who will be assigned to teach engineering chemistry course. Classroom observations were done to describe the instructional flows, teaching style and learning styles in the actual teaching of general chemistry. The general chemistry teachers employed the content-sensing, presentation-verbal, and perception-sequential teaching styles in all the meetings, participation-active teaching style was employed in most meetings while presentation-visual was employed the least. The teaching catered to sensing, verbal, sequential learning styles in all the meetings, to active learning style in most meetings, and visual learning style the least. The teachers used six (6) steps instructional flows with one to three cycles. This led to the theoretical formulation of the Five-Step, Five-Cycle Teaching model.

Tarhan, Ayar, Urek and Acar (2008) described in great detail their PBL success with a group of 9th grade chemistry students and 11th grade students. In groups, the 9th grade students worked on solving a chemistry problem centered on London dispersion forces. The teacher circulated around the room and asked guided questions as the groups worked on the problem. During group discussion, one group reasoned that tetrafluoroethylene‟s (Teflon) weak London dispersion forces made it difficult for food to stick to the pan. Other groups gave other real-life examples of London dispersion forces citing uses of graphite and oil. During the last 15 minutes of class, the teacher introduced new content that would be addressed in the next session. Chemistry students using PBL will develop 21st century workforce skills such as problem-solving, critical-thinking, self-guided learning, communication and teamwork. Process Oriented Guided Inquiry Learning (POGIL) is style of teaching that is designed to replace lectures in the classroom through a three-phase learning cycle. POGIL"s three phase learning cycle: 1) exploration phase, 2) concept invention to formation phase, and 3) application phase, all mirror the brain"s cognitive learning process for new information.

Aluko, (2008) investigated the relative effectiveness of cooperative instructional strategy on students" performance in secondary school chemistry. Two hundred and fifty (250) Senior Secondary two (SS II) chemistry students were purposively sampled from three public secondary schools in Ilesa Local Government Area of Osun State, Nigeria. Two research instruments: Researcher"s Instructional Packages (RIP) for solving Chemistry Problems and Chemistry Performance Test (CPT) were developed, validated and used for the study. The reliability of the Chemistry Performance Test (CPT) was determined and found to be 0.62 using the Pearson Product Moment Correlation formula. Three hypotheses were raised and tested using Analysis of Covariance (ANCOVA). The study covered a period of six (6) weeks. The experimental group, which is Cooperative instructional group and a Control group, were used. The results of the analysis showed that there was a significant difference in the performance of chemistry students exposed to cooperative instructional strategy and conventional teaching method. The cooperative instructional strategy was found to be more effective in enhancing better performance of the learners.

Danili and Reid (2012) explored some strategies to improve performance in school chemistry. Working with 105 Greek pupils aged 15 to 16, the first stage of the enquiry confirmed that both working memory space and extent of field dependency were two psychological factors affecting performance. This is at least part of the nature of the problem. In the second stage, an attempt was made to explore how the problems might be reduced. New teaching materials were constructed to minimize any limitations to learning caused by working memory space and problems associated with being field dependent. The use of the new materials was compared to the normal teaching process working with 210 Greek pupils aged 15 to16. It was found that there was a significant difference in the average improvement of the experimental group and the control group, in favour of the experimental group. This result was independent of the effect of the teacher, and of the interaction of teaching method and teacher. It is suggested that approaches to learning must take into account cognitive factors in the learners in the context of information processing understandings of learning. If this is done, learning is much more effective.

Ochonogor, (2011), investigated beyond the usual approaches of teaching chemistry by the educators in order to determine ways and practices that can positively influence the educators‟ teaching efforts and foster increased pass rate and quality of passes in Physical Sciences. Twenty-seven and 33 learners in their non-randomized intact classes were involved in the control and intervention classes respectively in two different high schools believed to have always underperformed at matriculation examinations in a suburb of Pretoria. The research made use of active learning model and a special form of cooperative learning strategy nick-named "goat and sheep method" with extra activities including animation to teach the experimental class and compared learners‟ performances with those of the control group that were taught the usual way. It was found out that upward of 87% of learners in the intervention class showed remarkably improved pass rate in quantity and quality in the post-test. In addition, the topics taught became more learner-friendly and the educator achieved higher confidence and proficiency in dealing with the subject. Proper application of the teaching method described in this study enhances chemistry educators" and learners" performances anywhere.

2.29 Conceptual Framework for the Study

Figure 15, presents the proposed conceptual framework of the study for the inferential statistical analysis. The framework illustrates the linkage between the dependent variables (level of understanding on hybridisation of molecules) and independent variables (5C"s teaching model). Students learn best through the 5C"s model of instruction.

The concept of the use of teaching methods in improving students" academic performance has been widely investigated by various researchers to try and pinpoint an exact or possible scientific relationship between teaching methods, and which factors truly cause consistent success among students. The conceptual model (Figure 15) depicts that students" level of understanding of hybridisation is dependent on teachers" teaching approach. The idea that teachers" teaching methods play a direct role in the achievement of students is not a new concept among the educational community. If a teacher maintains his/her personality, update knowledge, maintain class management, and adopt good communication skills during lessons, then it does not only help the students to learn well but will improve overall academics performance of the students.

Nevertheless, some teaching methods have been found to be ineffective in the teaching of abstract concepts in chemistry, in the case of this study – hybridisation of molecules. The conceptual model also holds the notion that the effective use of 5C"s model of teaching helps to develop students" interest, which in turn improves their level of understanding on the concept of hybridisation and examine how senior high school students" level of understanding on hybridisation of molecules can be improved with the use of 5C"s model of instruction.

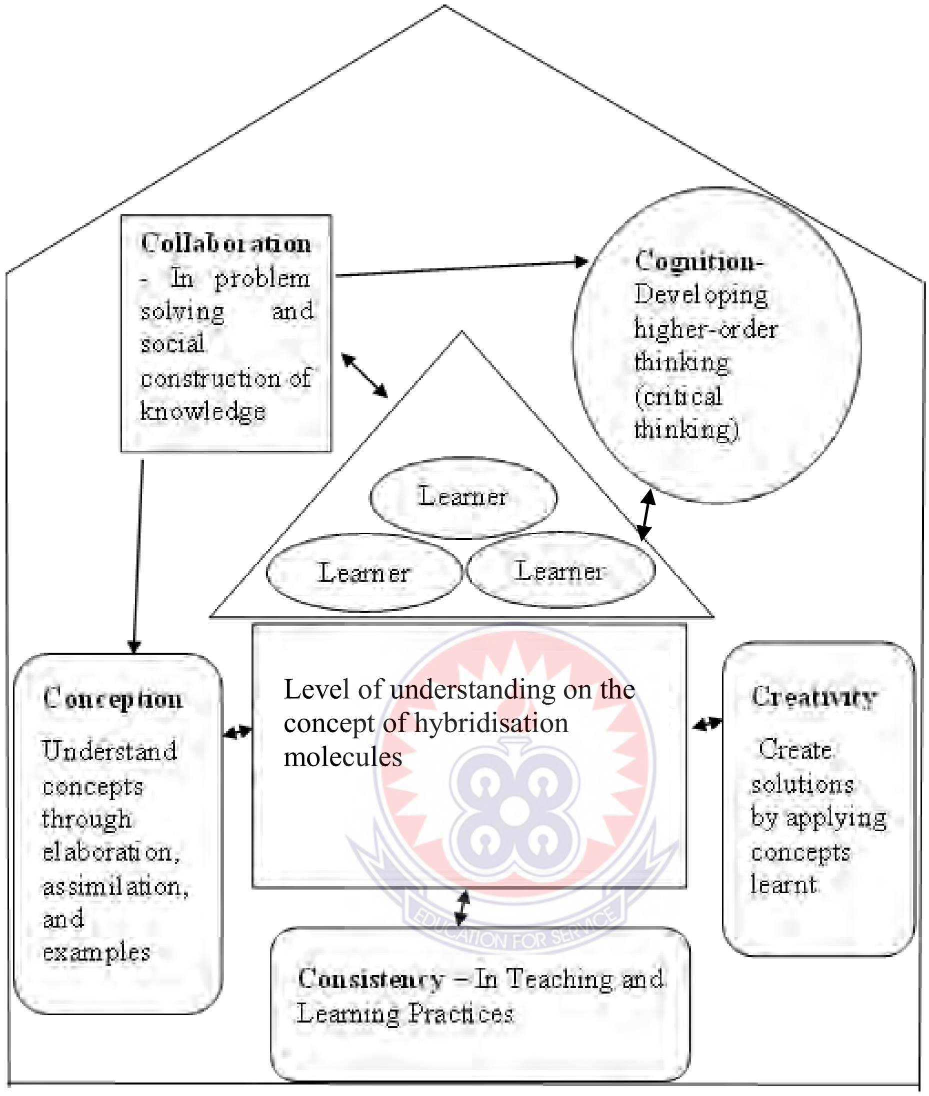

Figure 15: Conceptual Framework for the Study

Source: Tom (2015)

2.30 Chapter Summary

Chapter two reviewed literature that is very relevant to this research. It explored and gave more meaning to the contextual, theoretical foundations as well as empirical issues underpinning the phenomena being studied. The study embarked on the theoretical perspectives of Bandura"s Social Learning Theory, Jean Piaget"s

Cognitivist theory, and Vygotsky"s Constructivist Learning Theory. It is imperative to understand that the theory being discussed in this study may have been validated in some works of literature. The literature also includes studies on level of understanding on hybridisation of molecules among senior high school students, and effectiveness of the use of 5C"s model in improving students" learning and understanding on hybridisation of molecules. The chapter ended with a conceptual model, which summarizes the relationship between the key variables of the study and identified the gap bridged by the study.

CHAPTER THREE

METHODOLOGY

3.0 Overview

This chapter presents the research methodology. It captures the type of research design that was used in the explanation of the research problem. It identifies the study area, population, and sampling techniques. Data collection instruments and procedures, validity and reliability of instruments and data analysis are also captured in the research methodology.

3.1 Study Area

The study was conducted in the Cape Coast Metropolis. Cape Coast Metropolis is one of the seventeen (17) districts of the Central Region of south Ghana (Ministry of Local Government, Rural Development & Environment. Maks Publications & Media Services, 2007). The Metropolis is bounded to the South by the Gulf of Guinea, to the west by the Komenda Edina Eguafo Abrem Municipality District District, to the east by the Abura Asebu Kwamankese District, and to the north by the Twifu Heman Lower Denkyira District (see fig. 15). It is located on longitude 1° 15'W and latitude 5°06'N. It occupies an area of approximately 122 square kilometers, with the farthest point at Brabedze located about 17 kilometers from Cape Coast, the Central Regional capital (Ghana Statistical Services (GSS), 2021).

The Metropolis is the seat of the University of Cape Coast (UCC). It also has one of the best Technical Universities in Ghana. Other institutions of higher education in the city worthy of note are Mfantsiman Institute of Technology (MIT) and Institute of Development and Technology Management (IDTM). Twenty-three percent (23%) of the population live in rural localities. The total age dependency ratio for the metropolis is 49.1, the age dependency ratio for males is lower (48.2) than that of females (49.9) (GSS, 2021).

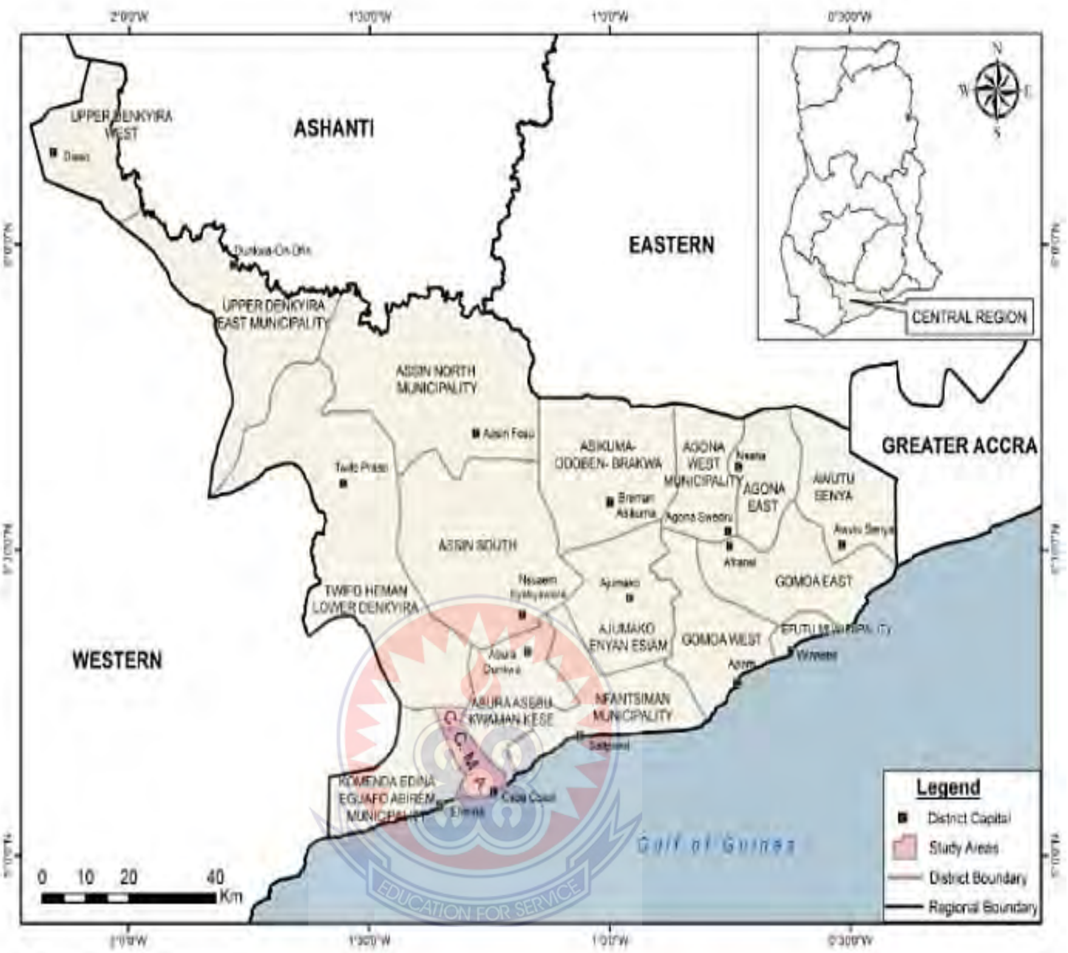

Figure 16: Cape Coast Metropolis in Regional and National Context

Source: Ministry of Local Government, Rural Development and Environment (2007)

The selected school was Ghana National Senior High School. Ghana National Senior High School was founded on 20th July, 1948 in Cape Coast, Ghana. The school was founded by the first Ghanaian President Kwame Nkrumah, for eight students who had been expelled by the British colonial administration from St Augustine's College. The school is located on a hill five miles east of the historic Castle town of Cape Coast right off the Accra – Takoradi highway. Ghana National Senior High School is a co-ed boarding secondary school (high school) with roots originally stemmed in the sciences but currently offering a wide range of core and elective high school courses from fine arts to languages and business. The school has a total population of close to thousand one hundred and forty-nine (3,149) students (Ghana Education Service, GES, 2021).

3.2 Research Design

This study was action research that determined how senior high school students‟‟ level of conceptual understanding on hybridisation of molecules can be improved with the use of 5C‟s model of instruction. In action research, the researcher tried to design or organise intervention(s) and uses it or them to curtail an identified situation that may be peculiar to a certain educational environment. The method is collaborative in nature and enables particular change conditions in a situation in which the researchers are personally involved Hardy, and Rönnerman, (2011) The goal of action research is both diagnostic as well as remedial.

Opoku-Asare, et al (2015). outlined four (4) reasons why it is useful to employ action research design in educational research works:

1. It helps to equip teachers with the opportunity of obtaining better comprehension of all aspects of their own practices, be it in relation to subject contents, the curriculum or the methods appropriate to the level of the students in a particular class.
2. It promotes teacher‟s personal development and the improvement of his/her practice
3. It helps the researcher to understand what actually goes on in the teaching learning situations

4. It provides the researcher with the skills of understanding the various approaches that best suits the learners in the classroom

Action research can inform teachers about their practice and empower them to take leadership roles in their local teaching contexts. That is, action research when conducted by a teacher focuses on identifying problems in the classroom and then to improve classroom practices in relation to that problem by the teacher himself. Based upon these features of action research, it was appropriate for this study. Action research enabled the students to learn from demonstration lessons.

According to Biggam (2015), the quantitative research approach aids the researcher in responding to queries about how a certain decision was made. Biggam (2015) further noted that this strategy aims to quantify variances to assess the amount to which an issue exists or the relationship that persist between features of a phenomenon. The quantitative method aided the researcher in avoiding bias in data collection and presentation. Qualitative research is an interpretative approach, which attempts to gain insight into the specific meanings and behaviours experienced in a certain social phenomenon through the subjective experiences of the participants. The use of both quantitative and qualitative methods of analysis tapped into the perception of teachers on students‟ level of understanding on hybridization and the effective use of 5C‟s model of instruction. This provided rich information or data for policy implementation and guidelines for schools in the Cape Coast Metropolis.

3.3 Population

Saunders and Lewis (2012) referred to population as a set of group members. According to Sawas, et al, (2018), the target population is the whole population in which a researcher is interested and to which he wishes to draw conclusions from the findings of a study. In this case, the population was made up of Form 2 science students from Ghana National Senior High School in the Cape Coast Metropolis. Form 2 science students were targeted because the subject of hybridisation is basically

studied in the second-year chemistry curriculum of secondary education. In selecting the sample, it is thought that the criteria considered to be important for the research topic are determined and according to these criteria, it is thought that the selected sample can represent the research universe with all its qualities. Table 1 below shows a breakdown of the population of Form 2 science students in the schools. There were 156 Form 2 science students from the selected school which comprises 92 males and 64 females.

Table 1: Population of Form 2 Science Students

Sexes of respondents	Student Population	Percentage (%)
Males	92	59
Females	64	41
	156	100

Source: Field Survey (2022)

3.4 Sampled Population

Sampling is the method of selecting units (e.g., individuals, organisations) from a population of interest so that we can reasonably generalise our findings back to the population from which they were selected by studying the sample (StatPac, 2012). Sampling is defined as the process of choosing a small group of respondents from a larger defined target population based on the assumption that the results discovered about the small group allow the researcher to draw conclusions concerning the larger group (Du Plooy-Cilliers, Davis & Bezuidenhout, 2014). The sample size was drawn based on the sample size table of Chuan, and Penyelidikan, (2006). This was used because its sample sizes are providing access to the most representative sample.

The sample was calculated with the help of a relatively large proportion of population (5%).

Formula for calculating the sample size =

$$\frac{X^2 \text{ x } N \text{ x } P \text{ x } (1-P)}{[d^2 \text{x } (N-1)] + [X^2 \text{ x } P \text{ x } (1-P)]}$$

X^2 = the table value of chi-square at 1 degree of freedom for the desire confidence level (3.841)

N = size of the population (number of Form 2 science students from the two schools (N = 156)

P = proportion of the population (assumed to be .50 since this would provide the maximum sample size)

d = the degree of accuracy expressed as a proportion (.05)

Therefore:

$$\text{Sample size} = \frac{X^2 \text{ x } N \text{ x } P \text{ x } (1-P)}{[d^2 \text{ x } (N-1)] + [X^2 \text{ x } P \text{ x } (1-P)]}$$

$$\text{Sample size} = \frac{3.841 \text{ x } 156 \text{ x } 0.50 \text{ x } (1-0.50)}{[(0.05)^2 \text{ x } (156-1)] + [3.841 \text{ x } 0.50\ (1-0.50)]}$$

$$\text{Sample size} = \frac{149.799}{} = 111.147$$

1.34775

The researcher used a sample of 110 students from the accessible population. More male students were selected due to the fact that, the population of male students in the school far outweigh that of the female students.

Table 2: Sampled Population of Form 2 Science Students

Sexes of respondents	Total	Percentage (%)
Males	65	59.1
Females	45	40.9
Total	110	100.0

Source: Field Survey (2022)

3.5 Sampling Procedure

The simple random technique was used by asking the participants one at a time to pick a number written on sheet of papers folded and kept in a basket. The participants picked a number, show it to class for recording and fold it back into the basket for another person to also pick. The picking was done in turns until no one is left out. All those having similar counting numbers were put in one group with the group bearing the name of the counted number picked by the each of the members. Members in such groups were enrolled in course sections which were designed by the researcher, who also served as instructor for the course and assess the performance output of the groups and individuals forming the groups. This relationship enhanced the administration and the data collection of the study.

3.6 Study Instruments

Data was gathered from primary sources. According to Salkind (2018), primary sources are interviews, questionnaires, tests, observations, eyewitness accounts, diaries, while secondary sources include reviews of research or syntheses of other works and general sources include daily newspapers, popular magazines, and indexes that provide an overview of the topic. According to Saunders and Lewis (2012), the selection of a research instrument depends on the purpose of the research. For the purpose of this study, data was gathered from the students using structured questionnaires, interviews and validated diagnostic test items.

3.7 Questionnaire

The items in the survey questionnaires required answers with ordinal or nominal values as well as open-ended questions. Closed-ended questions allowed the researcher to assess respondents‟ prior knowledge base and feelings, whereas open-ended questions enable the respondents to elaborate on their comments, qualify them, and clarify them Barr, and Copeland-Stewart, (2022). The questionnaire was developed to reflect the intended outcomes of the study. The questionnaire was made up of two (2) sections; A and B (see Appendix A). The first part, Section A, measured respondents‟ socio-demographic information such as gender, age, class or form. Section B assessed the level of understanding on the concept of hybridisation, awareness of hybridisation in molecules, and the use of information on molecules in modelling. This section was designed to understand students‟ motivation to master the course content and the benefits of the 5C‟s Model of instruction.

3.8 Interviews

Interviews with teachers were conducted (see Appendix B). The purpose of the interview was to enable the researcher to develop an understanding of the practices used by the teachers and reasons for using those practices. It also helped the researcher to gain a better understanding of the beliefs held and knowledge of the teacher about effective chemistry teaching. The interview helped the researcher to gather information from the teachers about their experiences of the 5C"s technique and the extent of engagement shown by their students during the learning tasks. The interview provided opportunities to identify any changes in teachers" practice and beliefs about effective chemistry teaching. These interviews were digitally recorded using a voice recorder. The recordings were imported into a computer, transcribed and analysed.

3.9 Chemistry Performance Test (CPT)

Chemistry Performance Test (CPT) was administered to all the students as a post-test at the end of the period. The test comprised of six main questions. They were stratified such that there are followed-up questions to the main ones. What makes pre-test and post-test data so useful is that, each subject can act as their own control making it easier to detect a significant treatment effect. In addition, open-ended questions were used to allow the students to provide clear explanations to the concepts. The first three questions assessed students" level of knowledge and understanding about atomic orbitals and hybrid orbital. Students were required to express the formation of sp, sp^2 and sp^3 hybrid orbitals from atomic s and p orbitals by shape.

Question four to six assessed students" understanding and application of hybridisation concept in practical situations. For this purpose, it was desirable for students to specify hybridisation of central atom in methane, ethane, and ethyne molecules with different hybrids. A maximum pass mark of 10 was allocated to each question. Misconception questions were identified and analysed. A sound knowledge of atomic orbitals and hybrid orbitals is a pre-requisite for understanding the concept of hybridization. Emphasis was placed on correcting students‟ misconceptions during the treatment period. Examples of the questions in the aforementioned are as follows:

1. Explain how you can define the concept of hybridisation.
2. Indicate the central atom hybridisation patter in methane, ethane, and ethyne molecules.
3. Explain how the atomic s and p orbitals overlap to form sp, sp^2 and sp^3 hybrid orbitals in a scheme.
4. Are compounds other than carbon also showing hybridisation? Explain with example.

3.10: Validity of the Instruments

According to Van der Riet and Durheim (2009), validity refers to the degree to which research conclusions are sound and based on credible results that can be used to make certain generalisations. To ensure validity, a copy of the questionnaire was sent to the research supervisor to see whether the number and form of items accurately measured the definition or construct of the instrument. Based on supervisor‟s comments, the researcher made the changes required. The items were adopted or modified from international tools and literature to meet the study concepts and objectives.

3.11: Reliability of the Instruments

The objective of reliability testing is to check that if a subsequent researcher employs the same protocols as those defined by the previous researcher and performs the same analysis again, the later researcher can arrive at almost the same results and conclusions Yin, (2009). It examines the amount of error variance in the test method and emphasizes on consistency, correctness and uniformity, the coefficient of reliability. The researcher performed a pilot study to check the reliability. The pilot study involved 30 science students who were not part of the actual experiment. This was to minimise errors and biases. Reliability was tested using Cronbach‟s alpha. The values obtained were 0.74 and 0.82 for pre-test and post-test respectively. Malan, et al., (2017), recommends a Cronbach‟s alpha coefficient value of 0.60 as the lower limit of acceptable Cronbach‟s alpha, with values above 0.8 preferable.

3.12 Data Collection Procedure

Throughout the study, traditional ethical issues in social science research were highlighted. In this analysis, the researcher followed human ethical guidelines, including informed consent, tolerance for anonymity and confidentiality, data storage and privacy, and transcript manipulation. The researcher sought for ethical approval from Science Education Department of the University of Education, Winneba that was sent to the schools to obtain their consent to conduct the study. All of the participants were issued informed consent forms to fill out and sign (see Appendix E). The researcher only included respondents based on their informed consent. Conducting of the research in the schools was approved and endorsed by the school management. The researcher communicated with the school authorities, teachers and students with respect to the purpose and nature of the study. All protocols in the data collection were explained to the respondents.

Data was collected within November 2021. The structured questionnaires were left with the class teachers, who at a convenient time gave them to the participating students. Answering of a questionnaire lasted between 20 and 30 minutes. The study intervention‟s specific implementation begun with researcher choosing students from a pool of willing applicants who completed the active consent process and demonstrated that they understood the research‟s purpose. Before each lesson, the researcher involved Chemistry teachers in each school in the designing and executing of the specified activities planned for each class to ensure their practicability and appropriateness. The researcher provided all the participants with learning materials such as A4 sheets, pencils and pens. The researcher and the Chemistry teachers then engaged the students in structured collaborative activities that allowed much step-by-step description of the activities and their outcomes.

The pre-test intervention was exposed only to the traditional teaching method without any reference to the use of 5C"s model of instruction in learning hybridisation of molecules. The aspects of hybridisation of molecules taught to the participants were (i) atomic orbital and (ii) the hybrid orbital. This intervention lasted for 5 days. At the end of the teaching period, Chemistry Performance Test (CPT) was administered to all the students. The CPT consisted of test items covering areas of knowledge, comprehension and application of hybridisation of molecules. The results obtained from this test was processed for statistical analysis. Scoring scheme designed by the researcher was used to assign scores to the outcome of activities performed by individual students.

Furthermore, the researcher developed instruction and administered to the participants using the 5C"s model of instruction in learning hybridisation of molecules.

The sessions within the intervention were designed based on one or more of the 5C"s model of cognition, conception, collaboration, consistency, and creativity. The aspects of hybridisation of molecules taught to the participants were atomic orbitals and hybrid orbitals. Participants were taught to understand bonding and shapes of some molecules. Formation of bonds within molecules in a hybridisation state is a pre-requisite for a main course offered by Form 2 science students. This lesson lasted for five days in three weeks. Participants were given a presentation on hybridisation to educate them on what hybridisation was and helped them understand the concept using 5C‟s model of instruction. Chemistry Performance Test (CPT) was administered to all the students as a post-test at the end of the teaching period. This consisted of test items covering areas of knowledge, comprehension and application of hybridisation of molecules.

Table 3 illustrates the pre-test and post-test interventions of the study.

Table 3: Pre-test and Post-test Interventions

Pre-Test	Post-test
Teaching hybridisation without the use of 5C‟s framework	Teaching hybridisation with the use of 5C‟s Framework
Lessons explaining hybridisation concepts and examples with very little interaction	Lessons explaining hybridisation concepts and examples with interactions
-	Explanation/Elaboration
-	Conceive and communication session
-	Interaction session: demonstration of concept application with examples
-	Collaborative problem solving/task completion

Source: Field Survey (2022)

3.13 Data Analysis

Completed responses from the questionnaires were sorted, cleaned, coded, and then transferred into the Statistical Package for Social Sciences (SPSS) Version 25 statistical analysis program. Descriptive statistics such as the mean, frequencies, and standard deviation was used to analyse research question one and two. The objective of descriptive statistics, according to Gitonga, (2017) is to allow the researcher to meaningfully define a distribution of scores or measurements using a few indices or statistics. Mean and standard deviation scores were determined to evaluate and compare the level of achievements of the two-cohort groups.

The researcher also adopted independent t-test analysis to analyse research question three. The motive is to determine the effectiveness of the use of 5C"s model in improving students" level of understanding in hybridisation of molecules by testing to find out whether to reject or fail to reject the null hypothesis. A P-value of <0.05 was deemed statistically significant. Open-ended data collected from the questionnaires was analysed by collating all the relative data, assimilating and categorizing similar responses and summarising the responses.

The audio recordings from the interviews and focus groups were listened to by the researcher, transcribed and the transcripts were read repeatedly until common patterns of responses emerged as themes. Journal entries and memo were used to describe the themes and quotations were selected to illustrate each. The data from the transcripts were reported in a narrative form and, supported with relevant quotes to enhance the credibility of the presented data.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Overview

This chapter presented data presentation and analysis findings to examine how senior high school students‟ level of understanding in hybridisation of molecules can be improved with the use of 5C‟s model of instruction. This chapter is organised into four sections – demographic characteristics of respondents, level of understanding in hybridisation of molecules, level of understanding on atomic orbital and hybrid orbital, and effectiveness of the use of 5C‟s model in improving students‟ level of understanding in hybridisation of molecules. Responses were captured from 110 students from Ghana National SHS in the Central Region of Ghana. A total of 110 questionnaires were distributed. Four chemistry teachers were interviewed to gather qualitative data on how students‟ level of understanding in hybridisation of molecules can be improved with the use of 5C‟s model of instruction. The completed questionnaires were edited for completeness and consistency. Of the 110 questionnaires used in the sample, 110 were returned represented a response rate of 100.0%, which the study considered adequate for analysis.

4.1 Demographic Characteristics of the Respondents

Table 4 presents results on the demographic characteristics of the students. The demographic characteristics capture gender and age group.

Table 4: Demographic Characteristics of Students (N = 110)

Variable	Frequency	Percentage (%)
Gender		
Male	65	59.1
Female	45	40.9
Age		
< 13 years	3	2.7
14 – 16 years	55	50
17 – 19 years	45	40.9
> 20 years	7	6.4

Source: Field Survey (2022)

Analysis from the study showed that more than half of the respondents (59.1%) were males as compared to their female counterparts (40.9%). However, it was found that the gender to the students was fairly distributed. It was revealed that half of the respondents (50%) were between 14 to 16 years, 40.9% were between 17 to 19 years, 6.4% were above 19 years, whereas only 2.7% were below 14 years.

Results Related to Research Questions Used

Research Question One: What is the level of students‟ conceptual understanding on hybridisation of molecules among senior high school students?

The first research question sought to determine the level of students‟ conceptual understanding in hybridisation of molecules among senior high school students in Cape Coast Metropolis. Participants‟ conceptual understanding of the concept of hybridisation was determined quantitatively through their expressions as presented in Table 5.

Table 5: Summary of Level of Students' Conceptual Understanding on Hybridization of Molecules

Response	Frequency	Percentage (%)
Sound understanding	7	6.4
Misconceptions of concept	58	52.7
No response	45	40.9
Total	110	100.0

Source: Field survey (2022)

Key:

Sound understanding = correct response and correct explanation

Misconception = correct response but wrong explanation or wrong response and wrong explanation

The simple percentages observed in Table 5, indicate that more than half of the participants (52.7%) had misconceptions of the meaning of hybridisation. Only 6.4% of the respondents had sound understanding of hybridisation, indicating that the term is the mixing of two or more native orbitals to form hybrid orbitals. However, 45 of the participants representing 40.9% did not answer the question at all. This misconception is reported in previous studies. Hanson, Sam, and Antwi (2012), for instance, reported that participants had gross misconceptions about hybridisation. Similarly, Çil and Uğraş (2015) found that respondents had misconceptions about hybridisation. As a result of analysis of data, it was determined that students describe hybridisation in four different categories. According to these categories, hybridisation is: (1) the mixing of atomic orbitals to form new orbitals suitable for bonding, (2) an electronic transition between orbitals, (3) an electronic transition between bonds, (4) a kind of covalent bond.

Table 6 gives an overview of participants" understanding on concepts of the types of hybridisations that exists in the central atoms of a given element or molecule.

Table 6: Prediction of Hybridisation of Sulphur Atoms in given Sulphur Molecules

Molecule	Type of Hybridisation	Correct	Wrong	No Response	Total
SO_2	Sp^2; bent	11(10)*	63(56.4)	36(32.7)	110(100)
SO_3	Sp^2; trigonal planar	10(9.1)	58(52.7)	42(38.2)	110(100)
SO_4^{2-}	Sp^3; trigonal pyramidal	21(19.1)	60(54.5)	29(26.4)	110(100)
SO_3^{2-}	Sp^3; tetrahedral	8(7.3)	50(45.5)	52(47.3)	110(100)

*The figures in parentheses ( ) denote percentages %

Source: Field survey (2022)

Findings from Table 6 indicates that the respondents generally performed poorly on prediction of hybridisation of sulphur atoms in given sulphur molecules. Majority of the respondents were unable to correctly indicate the types of hybridisations as shown in Table 6 above. This result shows a low level of understanding among the students on the concept of hybridisation. Qualitative data from the teachers in response to students" level of understanding on the concept of hybridisation also revealed misconception among the students. It was found that all the teachers interviewed were of the opinion that students have misconceptions of the concept of hybridisation.

One teacher asserted that students think:

"*Atoms undergo hybridisation because these atoms need electrons to satisfy the Octet Rule". ―Hybridisation is a process of an atom or molecule to complete the number of their valence electrons to eight*".

Explaining students" misconceptions about the concept of hybridisation molecules, one of the teachers echoed that:

"*We as teachers regard these abstract concepts as particularly challenging for students to learn and to reason about. Thus, these concepts are cognitively complex because people fail to handle mental manipulations needed. Studies reveal that learning abstract concepts is a difficult task and the cognitive complexity is one of the factors causing frustration and lack of interest to learn*".

Another teacher argued that:

"*Students make mistakes because their abstract concepts are not correctly structured and in particular do not support logical inferences. Students also have a tendency to apply the concepts mechanically instead of applying them meaningfully. Finally, students fail to actuate proper conceptual link at proper time.".*

Results from the study showed that there was low level of understanding among the students in hybridisation of molecules. This result of low level of knowledge was similarly reported in several studies. Sevgül (2018), for instance, revealed that most of the high school students had difficulty in explaining the formation of single, double and triple bonds using atomic and hybrid orbital knowledge and expressing it verbally and schematically. Again, Sevgül (2018) found that students have problems in identifying the hybridisation type which the central atom in the given organic compound undergoes. Similarly, Nyachwaya and Wood (2014) reported that some textbooks have chemical formulas and visual representations that can be used by students but the students misinterpreted these chemical formulas and visual representations. This proposed explanation provided a reason for how chemical formulas can support some students while failing to support other students in generating correct predictions.

Research Question Two: What is the level of students" conceptual understanding in atomic orbitals and hybrid orbitals?

The second research question sought to determine the level of understanding in atomic orbital and hybrid orbital among senior high school students. They were meant to assess the participants" understanding and their misconceptions about atomic orbitals and hybrid orbital. A sound knowledge of the concept of atomic orbitals and hybrid orbital is a pre-requisite for understanding the concept of hybridisation. A summary of participants" understanding as depicted through their responses is presented in Table 7.

Table 7: Summary of Understanding on Atomic Orbitals

Response	Frequency	Percentage (%)
Sound understanding	26	23.6
Misconceptions of concept	64	58.2
No response	20	18.2
Total	110	100.0

Source: Field survey (2022)

Results from Table 7 show that the majority of the participants had misconceptions about the concept of atomic orbitals. They scored a lower percentage of conceptual understanding; with only 26 participants (23.6%) out of the 100% participants exhibiting sound understanding of the concept. Interestingly, more than half of the respondents (58.2%) had misconceptions of the concept. About 18.2% of the respondents did not respond to the question.

The students were further tested on their level of understanding on why atomic orbitals undergo hybridisation. A summary of their responses is shown in Table 8.

Table 8: Summary of Why Atomic Orbitals Undergo Hybridisation

Response	Frequency	Percentage (%)
Sound understanding	22	20
Misconceptions of concept	60	54.5
No response	28	25.5
Total	110	100.0

Source: Field survey (2022)

Table 8 depicts that only 20% of the students had a conceptual understanding of why atomic orbitals undergo hybridisation. Most of them (54.5%) had misconceptions of the concepts, whereas 25.5% did not have any idea at all about why atomic orbitals undergo hybridisation. The teachers also attested to the misconception of the students on why atomic orbitals undergo hybridisation.

As noted by one of the teachers:

"*The most predominant misconception was the idea that electrons play the main role in hybridisation. This misconception was held by majority of the students. Some of the students even suggested that hybridisation was the overlapping of valence electrons. Besides this, some of them thought that it was a kind of electron sharing process. The rest of the students were observed to believe there was a relationship between hybridisation and electron passing among orbits or shells.*"

Another misconception about atomic orbitals was that:

"*The students perceived each orbital as a box, as in box diagrams or orbital filling diagrams used for electron configurations of multi-electron atoms. This misconception may result from the presentation of the orbital filling diagrams used for electron configurations in chemistry textbooks*". (Said by another teacher).

Table 9 presents summary of response on molecular orbital theory being a good model for explaining bonding in the NO molecule.

Table 9: Summary of Response on Molecular Orbital Theory Being a Good Model for Explaining Bonding in the NO Molecule

Response	Frequency	Percentage (%)
Sound understanding	11	10
Misconceptions of concept	46	41.8
No response	53	48.2
Total	110	100.0

Source: Field survey (2022)

According to Table 9, participants exhibited poor knowledge on „Molecular orbital theory". It was found that 46 respondents representing 41.8% had misconceptions whilst 11 respondents representing 10% had sound understanding on whether the molecular orbital theory could adequately explain the kind of bonding in the NO molecule. The highest „no response" to an item was recorded here. As many as 53 respondents (48.2%) failed to supply answers to the test item. This result holds the notion that students were unable to identify whether molecular orbital theory could explain bonding in the NO molecule. This stand corresponds with past work where chemistry major students focused on structural features while classifying representation. One of the studies carried out by Farheen and Lewis (2021) showed that with bond length, students were less likely to cite bond order. Across all the chemical properties, students were no more likely to cite shape of molecule.

Furthermore, the study assessed students" level of understanding for difference between hybrid orbital and pure atomic orbital (Table 10).

Table 10: Summary of Response for Difference Between Hybrid Orbitals and Pure Atomic Orbitals

Response	Frequency	Percentage (%)
Sound understanding	12	10.9
Misconceptions of concept	46	41.8
No response	52	47.3
Total	110	100.0

Source: Field survey (2022)

Table 10 reveals that more than half of the respondents (47.3%) had virtually no idea at all about the differences between hybrid and pure atomic orbitals. Forty-six (46) respondents representing 41.8% had poor understanding, whereas only 10.9% of them had sound understanding about the differences between hybrid and pure atomic orbitals. The results are similar to those obtained for the meanings of „hybridisation" and „atomic orbitals" This confirms the alternative conceptions that students hold on the terms „hybridisation" and „atomic orbitals".

One of the teachers revealed that:

"*Many of the students cannot distinguish between pure atomic and hybrid orbitals. Most students show absolutely no understanding of the concept. Neither are they able to predict the hybridised state of sulphur in* $S0_3$".

Another teacher argued that:

"*Most of the high school students had difficulty in explaining the formation of single, double and triple bonds using atomic and hybrid orbital knowledge and expressing it verbally and schematically. They also have problems in identifying the hybridisation type which the central atom in the given organic compound undergoes".*

One teacher believed that:

—*Students fail to understand concepts particularly when reasoning about them in real time because their focus is on the mechanical application of a rote learnt procedure rather than a meaningful understanding of the concepts".*

The study found that there was misconception on atomic orbital and hybrid orbital among senior high students in Cape Coast. Hanson, Sam and Antwi (2012) also opined that there were misconceptions about hybrid orbitals among respondents. Based on these results, it is important to explain hybrids in detail at a high school level, taking advantage of teaching techniques and materials, paying attention to visuality during teaching and exploiting three-dimensional models.

Students were asked to identify the challenges they face in understanding hybridisation of molecules. Their responses are presented in Table 11.

Table 11: Challenges Encountered by Students in Understanding Hybridisation

Variables	Frequency	Percentage (%)
The use of lecture method and no book to revise from	19	8.9
Lack of assignments and activities	11	5.2
Teaching was mostly lecturing	60	28.3
Difficult in getting concept because of traditional method used	82	38.7
Inadequate reading materials	16	7.6
Lost interest due to general poor performance	24	11.3
Total response	212*	100.0

*Multiple response; N = 110

Source: Field survey (2022)

The study shows that majority of the respondents were of the opinion that the use of traditional method of teaching makes it difficult in understanding the concepts of hybridisation (38.9%). Portion of the respondents (28.3%) also indicated that teaching of hybridisation is mostly lecturing which affects their level of understanding of the concept. Interview with the teachers also revealed similar results.

According to two teachers:

"*Students have difficulties in getting concepts, because of lecturing method used and inadequate teaching and reading materials".*

―*Students lose interest in abstract concepts due to general poor performance. They exhibit difficulties in understanding the concepts".*

The results point out that students are less likely to engage in chemical conventions, such as determining bond order when solving bond length or determining polarity when solving intermolecular forces, when given chemical formulae. It was also noted that a small proportion of students attribute molecular shape as an explicit property of Lewis dot structures which hinders making chemical predictions reliant on shape. These findings are consistent with past research literature documenting student challenges in understanding hybridisation of molecules (Cooper et al., 2010; Wang & Barrow, 2013). Claesen, Valkenborg, and Burzykowski (2020) proposed that the mass and intensity accuracies of the observed aggregated isotopic variants are insufficient to accurately predict the number of atoms. Farheen and Lewis (2021) reiterated that an example of reliance on chemical conventions leading to potential mistakes is the higher rate of citing resonance with chemical formula than other representations.

Prior literature indicates that promoting students" engagement with the representation can boost performance on tasks (Talanquer, 2017), thus, it is possible that promoting student engagement with these representations can improve students correct prediction of chemical properties when provided with these representations. It is also possible that the enactment of visual estimations can lead to incorrect predictions as students might make an inaccurate visual estimate of the representation given or may be cued to features that are unrelated to the chemical property. The lack of a sizable difference in correct percentage when students cited the feature visual estimation does not support this, but the code visual estimation was conservatively applied to only the responses that made a clear description particularly to the image provided (Farheen & Lewis, 2021). Consequently, this study asserts that it is important for teachers to explain hybridisation in detail to students, taking advantage of good teaching techniques and materials.

Research Question Three: How effectiveness is the use of 5C"s model in improving students" conceptual understanding in Hybridisation of molecules?

The third research question was to examine the effectiveness of 5C"s model of teaching and learning in improving the conceptual understanding of hybridisation of molecules among senior high school students in the Central Region of Ghana. Statistical analysis was conducted to determine whether learning took place when using the 5C"s model of teaching and learning. An independent-sample t-test was conducted to compare the knowledge scores for pre-test and post-test on hybridisation among senior high school students and to test the null hypothesis and find out whether to reject or fail to reject the null hypothesis. Table 12 presents results on the comparison of pre-test and post-test mean level of understanding in hybridisation among senior high school students between 5C"s model and traditional method of teaching.

Table 12: Effectiveness of 5C's Model in Understanding of Hybridisation

	Pre-Test		Post-Test			
	Mean	**Std. Deviation**	**Mean**	**Std. Deviation**	**t-Test**	**p-value**
Traditional Method	18.92	3.84	21.55 mean difference = 2.63	3.98	3.4837	2.635
5C"s Model	19.15	3.99	24.82 mean difference = 5.67	4.02	5.0379	

Source: Field survey (2022)

Table 12 shows that there is an increase in level of conceptual understanding regarding hybridisation of molecules by using the traditional method of teaching as the mean value increased from 18.92 (pre-test) to 21.55 (post-test). Statistically, traditional method of teaching is found to be effective as the mean difference is 2.63 in enhancing the conceptual understanding in hybridisation among senior high school students. Again, the study also found that there was a significant increase in level of conceptual understanding regarding hybridisation by the use of 5C"s model of teaching as the mean value increased from 19.15 (pre-test) to 24.82 (post-test) with a mean difference of 5.67 as shown in Table 12. The analysis of the results showed clearly that the use of 5C"s model of teaching was more effective than the traditional method of teaching (post-test mean score difference of 5.67 and 2.63 respectively). To determine the significance of the effectiveness of the use of the 5C"s model in improving students" conceptual understanding in hybridisation of molecules, an independent t-test analysis was conducted. With a test statistic (alpha) of 0.05 and a degree of freedom of 9, a p-value (calculated) of 2.635 and t-value (tabulated) of 1.833 were obtained. Since the p-value (calculated) is larger than the t-value (tabulated), it means there was a significant difference between the pre and post interventional scores for the experimental group. Therefore, the null hypothesis is rejected. This means that, the 5C"s model of instruction significantly improved students" conceptual understanding in hybridisation of molecules.

Sarpong (2015), for instance, showed that students face difficulties to comprehend molecular and hybridisation geometries when presented to them in theoretical manner. It was found that conventional teaching approach makes concepts difficult for students to comprehend. Similarly, Aluko (2008) reported that there was a significant difference in the performance of chemistry students exposed to cooperative instructional strategy and conventional teaching method. The cooperative instructional strategy was found to be more effective in enhancing better performance of the learners. Danili and Reid (2012) found that there was a significant difference in the average improvement of the experimental group and the control group, in favour of the experimental group. They concluded that approaches to learning must take into account cognitive factors in the learners in the context of information processing understandings of learning.

Another study by Tom (2015) found that the use of the 5C"s teaching framework transforms the learning to an enriching and enjoyable experience, developing a deeper understanding with improved cognitive skills, and development of soft skills such as team work, communication, and oral presentation. Tabinas (2019) argued that the 5C"s teaching model guides teachers assigned to teach chemistry course. According to the author, chemistry teachers employed the content sensing presentation - verbal, and perception - sequential teaching styles in all the meetings, participation - active teaching style was employed in most meetings while presentation - visual was employed the least. Ochonogor (2011) made use of active learning model and a special form of cooperative learning strategy and found that upward of 87% of learners in the intervention class showed remarkably improved pass rate in quantity and quality in the post-test.

A descriptive statistic was carried out to determine both students and teachers" perception on the level of effectiveness of traditional teaching method and the use of

5C‟s model of teaching hybridisation of molecules. Their responses are presented in Table 13 below.

Table 13: Students' Perception on Effectiveness of 5C's and Traditional Methods of Teaching Hybridisation of Molecules

Teaching Method	Highly Effective	Very Effective	Effective	Somehow Effective	Not Effective	Total
Traditional method	10(9.1)*	12(10.9)	38(34.5)	39(35.5)	11(10)	110(100)
5C‟s module	24(21.8)	40(36.4)	26(23.6)	15(13.6)	5(4.6)	110(100)

Source: Field survey (2022)

*The figures in parentheses ( ) denote percentages %

With reference to Table 13, 34.5% of the respondents indicated that the use of traditional method in teaching hybridisation of molecules is effective, 10.9% noted that it is very effective, whereas 9.1% said the method is highly effective. On the contrary, 35.5% said that it is somehow effective and 10% said it is ineffective. In terms of the use of 5C‟s method of teaching, the study found out that most of the respondents (36.4%) were of the opinion that this method is very effective in teaching hybridisation of molecules.

These assertions were also confirmed by the teachers. They revealed that 5C‟s was effective in teaching of hybridisation of molecules.

One teacher stated that:

"*Sessions within each pack are designed based on one or more of the Five C constructs of cognition, conception, collaboration, consistency, and creativity. These packs of four different sessions systematically guide the student from their origin, with little or no knowledge, to their destination where the students feel very comfortable with the new idea and its application*".

It was also revealed by another teacher that:

"*5C's promotes cultivation of creativity and communication skills.*

Another teacher said:

―*Students who engage in a creative activity within the constraints of time and environmental elements and working beyond the constraints of current norms/boundaries goes through a process transforming his/her knowledge into a product that is fulfilling for the student*".

These findings agree with other studies. According to Butt (2018), that effective teaching is dynamic, receptive, responsive and approachable, not static and over programmed; meaning that teachers" pedagogical knowledge should not be static but must change in response to the content and the learners with whom it is being shared. A study by de Johnson, (2011), suggests that lecture leads to the ability to recall facts and this is because the individual is able to memorize whatever he or she is taught in class.

The study further sought to examine students" perception on the effective method of teaching hybridisation of molecules. Table 14 presents perception of students on effective teaching method for hybridisation of molecules.

Table 14: Perception of Students on Effective Methods of Teaching Hybridisation

Variables	Frequency	Percentage (%)
Traditional method is effective way of learning than 5C"s		
Yes	27	24.5
No	83	75.5
Traditional method is relevant to development than 5C"s		
Yes	21	19.1
No	89	80.9
Traditional method is participatory and interactive		
Very participatory and interactive	9	8.2
Participatory and interactive	21	19.1
Somehow participatory and interactive	18	16.4
Not participatory and interactive	62	56.3
5C"s is participatory and interactive		
Very participatory and interactive	26	23.6
Participatory and interactive	67	60.9
Somehow participatory and interactive	4	3.6

Not participatory and interactive	13	11.8

Table 14 : Cont'd

Variables	Frequency	Percentage (%)
Teaching method that monitors and gives feedback		
Traditional method of teaching	39	35.5
5C"s method of teaching	71	64.5
Teaching method that motivates students to pursue learning		
Traditional method of teaching	42	38.2
5C"s method of teaching	68	61.8

N = 110

Source: Field survey (2022)

Table 14 depicts that few of the respondents (24.5%) opined that traditional method of teaching is a more effective way of learning than 5C"s method. It was also found that 80.9% disagreed to the assertion that traditional method rather than 5C"s method is more relevant to their personal development. Only 27.3% of the respondents stated that traditional method is participatory and interactive, whereas 84.5% of them agreed that the 5C"s method is participatory and interactive. More than half of the respondents (64.5%) reported that the 5C"s method monitors and gives feedback on students" mastery of learning. It was also revealed that about 61.8% said the 5C"s method motivates students to pursue learning activities and stimulate thinking. Students are able to recall everything when he or she goes back to read whatever is taught. The 5C"s model on the other hand produces higher level comprehension when the student is expected to deliberate on what has been taught in class. Students participate and contribute in class especially when they are asked to set examples or explain a concept they know of.

According to Tom (2015), the use of the 5C‟s model reduced negative emotional issues, motivated students to become active learners, and improved the overall performance. He continued that 5C‟s provided a model for student-centered teaching pedagogy which helped to minimise complexities for diverse student cohorts. Similarly, Tarhan, et al., (2008), recommended a process oriented guided inquiry learning teaching style which is designed to replace lectures in the classroom through a three-phase learning cycle – exploration, concept invention to formation, and application phase. As described by Tarhan, Ayar, Urek, and Acar (2008), this approach like the 5C‟s model helped students to develop skills such as problem solving, critical thinking, self-guided learning, communication and teamwork. According to Ochonogor (2011), topics taught with 5C‟s model become more learner-friendly and the educator achieved higher confidence and proficiency in dealing with the subject. Proper application of the teaching method described in this study enhances chemistry educators‟ and learners‟ performances.

Consequently, the students‟ level of satisfaction was assessed on a 4-point Likert scale ranging from very high to very low as shown in Table 15. For the purpose of discussions, the responses are categorised into two groups – high and low.

Table 15: Level of Satisfaction with Methods of Teaching Hybridisation

	Level of Satisfaction				
Teaching Method	**Very high**	**High**	**Low**	**Very Low**	**Total**
Traditional method	21(19.1)*	32(29.1)	38(34.5)	19(17.3)	110(100)

5C‟s Method	55(50)	38(34.6)	12(10.9)	5(4.5)	110(100)

Source: Field survey (2022)

*The figures in parentheses ( ) denote percentages %

Table 15 shows that 48.2% of the respondents indicated that their level of satisfaction with the use of traditional method in teaching hybridisation was high. More than half of the respondents (51.8%) were dissatisfied with the use of traditional method in teaching the concept of hybridisation molecules. In terms of the use of 5C‟s model in the teaching of hybridisation of molecules, majority of the respondents (84.6%) indicated that they were highly satisfied with the model, whereas only 15.4% were dissatisfied with this model.

The students were asked to indicate their level of preference with regards to the discussion and lecture method of teaching. Table 16 presents the results of respondents‟ preference of method of teaching.

Table 16: Respondents' Preference of Method of Teaching Hybridisation

Teaching Method	Frequency	Percentage (%)
Traditional Method	21	19.1
5C‟s Method	89	80.9
Total	110	100

Source: Field survey (2022)

As noted in Table 16, majority of the respondents (80.9%) indicated that they preferred the use of 5C‟s method in the teaching and learning of hybridisation of molecules to the traditional method of teaching. The reason cited for this preference was that the 5C‟s method made it easier for them to contribute in class as compared to the traditional method. The respondents also noted that it provided deeper understanding and sharing of ideas, exposure to new ideas, enriching experience, clarification of doubts, improved confidence, helped to structure knowledge, made learning more interesting, and fun. Similarly, Sarpong (2015) founded that 5C"s model enhanced students" academic performance and argumentative skills far better than the conventional teaching approach. When students were taught through this model, it built their visuo-spatial thinking (thinking through imaginations), developed their creative thinking skills, created competition in learning among students, developed speaking and presentation skills of students, enhanced the argumentative skills of students, and also prepared them to become tolerant towards others" views.

CHAPTER FIVE

SUMMARY OF FINDINGS, CONCLUSIONS, RECOMMENDATIONS, SUGGESTIONS AND SUGGESTIONS FOR FUTURE STUDIES

5.0 Overview

This chapter gives the summary of the findings, conclusions, and the way forward in the form of recommendations. The recommendations put forward took into consideration the findings and conclusions of the study. This, if diligently executed, will go a long way to improve senior high school students‟ level of conceptual understanding in hybridisation of molecules.

5.1 Summary of Findings

The main objective of the study is to examine how senior high school students‟ level of conceptual understanding on hybridisation of molecules can be improved with the use of 5C‟s model of instruction. An action research design was adopted using both descriptive and inferential approaches. The study targeted senior high schools in the Cape Coast Metropolis. The selected school was Ghana National Senior High School. The simple random sampling technique was used to sample the students on their readily availability to the study. A sample of 110 students was included to participate in the study.

Their responses were sought with the help of a structured questionnaire. Objective one sought to assess the level of conceptual understanding on hybridisation of molecules among senior high school students and revealed that there was low level of understanding among the students on the concept of hybridization of molecules. Only 6.4% of the respondents had sound understanding of hybridisation. Majority were unable to indicate the types of hybridisation.

Objective two examined the level of understanding of senior high school students on atomic orbitals and hybrid orbitals. It was found that majority of the students had misconceptions on atomic orbitals and hybrid orbitals which were pre-requisite for understanding the concept of hybridisation. Method of teaching was identified by the students as one of the major challenges associated with low level of understanding of the concept.

Objective three sought to determine the effectiveness of the use of 5C‟s model in improving students‟ level of understanding on hybridisation of molecules and revealed that 5C‟s model is important in teaching hybridisation of molecules. There was a significant increase in level of knowledge regarding hybridisation of molecules by 5C‟s model of teaching (p-value = <2.635). The mean value of instruction by using the 5C‟s model increased from 19.15 (pre-test) to 24.82 (post-test) and the mean difference of 5C‟s model was 5.67.

5.2 Conclusions

This study concludes that the overall level of understanding in hybridisation of molecules among senior high school students is low. Students‟ pre-requisite knowledge in learning about hybridisation is inadequate. The concepts of atomic orbital and hybridisation are among the chemistry topics that students have difficulties in learning because of their abstractness. However, the use of 5C‟s teaching model is effective in improving students‟ level of understanding of the concept of hybridisation. The framework is based on the perspective that learning is a socially embedded cognitive process and knowledge is socially constructed through interaction and activity with others. Therefore, the traditional method of teaching hybridisation of molecules is not friendly to students. Poor and unfriendly pedagogical practices such as the use of lecture method only, reading from pamphlet while explaining to students contribute to low understanding of hybridisation of molecules. The use of 5C‟s model, on the other hand, makes it easier for students to think of molecules in three dimensions and increases interest in the subject and more effective learning of students about hybridisation. The building constructs of 5C‟s – consistency, collaboration, cognition, conception, and creativity, transforms the authoritative role of the teacher to a guide and empowers students with active learning and leadership skills. In addition, it provides deep understanding, sharing of ideas, exposure to new ideas, enriching experience, clarification of doubts, improved confidence, helped to structure knowledge, made learning more interesting, and fun. The 5C‟s model if effectively utilised to teach different concepts in chemistry would have a positive impact on teaching and learning of chemistry.

5.3 Recommendations

Based on the findings, the following recommendations were made to improve the teaching and learning of hybridisation of molecules among senior high school students in the Cape Coast Metropolis.

1. The traditional expository mode of teaching is common in chemistry classrooms in the Cape Coast Metropolis, as teachers tend to teach in the same way that they were taught making learners passive learners. It is important that teachers adequately plan lessons, which include multiple representation, challenging activities that actively engage students as this will help avoid simple rote learning.
2. The study also recommends the adoption of the 5C‟s; consistency, collaboration, cognition, conception, and creative teaching and learning

approaches to be used by teachers in Cape Coast Metropolis to allow students develop deep understanding, share new ideas and experiences, clarify doubts, develop confidence, and structure their knowledge. This will help make teaching and learning of hybridization of molecules more interesting and fun which will in turn improve the performances of students.

3. The study therefore recommends the need to adopt the 5C‟s model of instruction in the teaching and learning of chemistry at the senior high school level.

5.4 Suggestions for Further Research

The following suggestions were made for future investigations:

1. This study was limited to students from two senior high schools in the Cape Coast Metropolis. The study recommends further studies on the subject matter to be carried out across the country to unearth further investigations for quality improvement in other senior high schools.
2. In addition, the study was limited to the study of hybridisation. Therefore, it is suggested that further studies on the effective use of 5C‟s model in teaching and learning in improving students‟ performance should be carried out in other chemistry topics. This will provide comprehensive conclusion about the effectiveness of the 5C‟s model in teaching other chemistry topics.

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APPENDIX A

QUESTIONNAIRE FOR STUDENTS

This questionnaire is designed to elicit information on how senior high school students" level of understanding on hybridisation molecules can be improve with the use of 5C"s module of instruction. This is solely for academic purposes, therefore, all the information you provide will be stored confidentially and securely in accordance with data protection policies. This study is anonymous so you do not need to provide your name. I am therefore asking if you could answer the following questions by ticking in the boxes (√) or writing in the spaces provided where applicable. Thank you.

SECTION A: DEMOGRAPHIC CHARACTERISTICS

1. Gender:

   Male ( ) Female ( )

2. Age:

   < 13 years ( ) 14 - 16 years ( ) 17 – 19 years ( )

   > 20 years ( )

SECTION B: UNDERSTANDING IN HYBRIDISATION OF MOLECULES

3. Which of the following statements best describes the concept of hybridisation?

   Bonding of atomic orbitals to give rise to molecular orbitals ( )

   Combination of two or more ionic substances ( )

   Combination of two or more orbitals to give a stable species ( )

   It is the mixing of atomic orbitals ( )

   It is the mixing of two or more native orbitals to form hybrid orbitals ( )

   Mixing of atomic orbitals of different shapes ( )

Mixing of two or more electrons ( )

Mixing up of two or more atoms ( )

Mixture of atomic orbitals of two or more atoms ( )

Overlapping of atoms to form stable bonds ( )

The paring of more than one atom ( )

4. What are the types of hybridisation that exists in the central atoms of the given species?

SO_2 _______________

SO_3 _______________

SO_4^{2-} _______________

SO_3^{2-} _______________

SECTION C: UNDERSTANDING ON ATOMIC ORBITALS AND HYBRID ORBITALS

5. Which of the following statements best describe the concept of atomic orbitals?

A hollow space; spaces in an element where atoms occupy ( )

Mixing of orbitals ( )

Orbitals of the same energy ( )

Orbitals used in bonding ( )

Orbitals which differ from one state to another ( )

Pathway that atoms trave; ( )

Shells made up of the same kind of atoms ( )

Space around nucleus where there is a high probability of locating electron ( )

Sub shells of a principal energy level which has the same energy ( )

They are the number of shells ( )

Where electrons can be located ( )

6. Which of the following statements best describe why orbitals undergo hybridisation?

Different orbitals have different energies ( )

Different orbitals have different energy and shape ( )

They contain charged particles ( )

They undergo hybridisation when they bond with other orbitals ( )

To form a single or multiple bond ( )

To form pi and sigma bonds and their geometry ( )

To form some bond ( )

To give equal energy levels ( )

To know their molecular structure ( )

To obtain inert gas structure or octet rule ( )

To obtain overall stability ( )

7. Which of the following statements best describe why molecular orbital theory being a good model for explaining bonding in the NO molecule?

Because it can have more than one orbital ( )

Hybrid orbitals only exist when there is to be bonding or mixing of different orbitals for bonding ( )

Isolated atoms do not have bond with any other atoms ( )

It does not mix with its own orbitals ( )

It is single and there is no bond existing ( )

It is unstable difference in energy ( )

It must be stable at ground state ( )

There is no sharing of electrons ( )

8. Which of the following statements best describe difference between hybrid orbital and pure atomic orbital?

   Hybrid orbital involves overlapping of orbitals while pure atomic orbitals do not ( )

   Hybrid orbitals obey the octet rule but atomic orbitals do not ( )

   Character and energy different from native atomic orbitals so it is more stable ( )

   Orientation of their shapes ( )

   They contain overlap of two orbitals ( )

   They differ in size, shape and energy ( )

   Because of their molecular structure ( )

9. What are some of the challenges you encountered during lessons in hybridisation molecules?

   …………………………………………………………………………………………

   …………………………………………………………………………………………

   …………………………………………………………………………………

SECTION D: USE OF 5C"s MODEL IN IMPROVING STUDENTS" LEVEL OF UNDERSTANDING ON HYBRIDISATION OF MOLECULES

10. Indicate by ticking the appropriate level of effectiveness of these two teaching methods in hybridisation molecules.

A. Traditional method

   Highly Effective ( )

   Very Effective ( )

   Effective ( )

Somehow Effective ( )

Not Effective ( )

B. 5C"s model

Highly Effective ( )

Very Effective ( )

Effective ( )

Somehow Effective ( )

Not Effective ( )

11. Would you say that traditional method of teaching rather than 5C"s is a more effective way of learning?

Yes ( )

No ( )

12. Would you say that traditional method of teaching rather than 5C"s is more relevant to your personal development?

Yes ( )

No ( )

13. To what extent do you agree that participatory and interaction is encouraged in traditional method of teaching and 5C"s method of teaching

A. Traditional method of teaching

Very participatory and interactive ( )

Participatory and interactive ( )

Somehow participatory and interactive ( )

Not participatory and interactive ( )

B. 5C"s method of teaching

Very participatory and interactive ( )

Participatory and interactive ( )

Somehow participatory and interactive ( )

Not participatory and interactive ( )

14. Which of the methods of teaching do you think monitors and give feedbacks on students‟ mastery of learning?

Traditional Method of Teaching ( )

5C‟s method of Teaching ( )

15. In your opinion, which of the methods of teaching motivates students to pursue learning activities and stimulate thinking?

Traditional Method of Teaching ( )

5C‟s method of Teaching ( )

16. Tick the appropriate level of satisfaction of the two teaching methods in teaching hybridisation of molecules.

A. Traditional Method of Teaching

Very High ( )

High ( )

Low ( )

Very Low ( )

B. 5C‟s Method of Teaching

Very High ( )

High ( )

Low ( )

Very Low ( )

17. Which of the methods of teaching do you prefer in the teaching and learning of hybridisation molecules?

Traditional method ( )

5C‟s method ( )

18. Give reasons

………………………………………………………………………………………

………………………………………………………………………………………

APPENDIX B

INTERVIEW GUIDE FOR TEACHERS

This interview schedule is designed to elicit information on how senior high school students‟ level of understanding on hybridisation molecules can be improve with the use of 5C‟s module of instruction. This is solely for academic purposes, therefore, all the information you provide will be stored confidentially and securely in accordance with data protection policies. This study is anonymous so you do not need to provide your name, your place of work, or any identifiable details of the people you work with. Thank you.

1. Please tell me something about yourself in terms of educational background, age, marital status, and number of years spent in this school.
2. Generally, how you describe your students‟ level of understanding on hybridisation of molecules.
3. What are some of the misconception students‟ hold on the concept of hybridisation?
4. Are students able to identify the types of hybridisation that exists in the central atoms of a given species?
5. What is the level of your students on atomic orbitals and hybrid orbitals?
6. What misconceptions do students frequently associate with atomic orbitals and hybrid orbitals?
7. What challenges do students encounter during lessons in hybridisation of molecules?
8. What teaching models do you employ in your chemistry lessons?
9. Probe for reason(s) for the use of the models.
10. Do you think 5C‟s model is effective in teaching hybridisation of molecules compared to the traditional teaching method?
11. Probe for reason(s) for answer.

12. Explain how you utilize the 5C‟s model in teaching hybridisation of molecules.

13. Do you think the 5C‟s engages students to participate and interact in class?

14. Probe for reason(s) for answer.

APPENDIX D

POST-TEST INTERVENTION

1. How can you define the concept of hybridisation?

2. Differentiate between atomic orbital and hybrid orbital and give examples.

3. Draw the shapes of the s and p orbitals and show their orientations.

4. State the type of hybridisation exhibited by the central atoms in the following molecules:

	Name	Structure	Types of Hybridisation	Geometry
f.	Methane	—C— (with bonds above and below)	……………………	………..
g.	Ethene	C = C (with two bonds on each carbon)	……………………	………..
h.	Ethyne	—C ≡ C—	……………………	……….
i.	Hydrogen cyanide	H—C ≡ N	…………………	………
j.	Carbon dioxide	O = C = O	…………………	………..
d.	Ammonia	H — N — H (with H below N)	………………	……...

5. Describe how sigma and pi bonds are formed.

6. With the aid of appropriate diagrams, indicate how the s and p orbitals overlap to form sp^3, sp^2 and sp hybrid orbitals.

APPENDIX E

INFORMED CONSENT FORM

Part 1

As part of my study for masters‟ degree at the University of Education, Winneba, I have to collect data as a practical part of my research work for which I need your assistance.

Title of the THESIS:

USING THE 5C‟s MODEL OF INSTRUCTION TO IMPROVE STUDENTS‟ CONCEPTUAL UNDERSTANDING IN HYBRIDISATION OF MOLECULES.

The thesis sought to:

Examine how senior high school students‟ level of understanding on hybridisation molecules can be improved with the use of 5C‟s module of instruction.

In achieving the objective of the study, the researcher seeks to answer the following questions:

1. What is the level of understanding on hybridisation molecules among senior high school students?
2. What is the level of understanding of senior high school students on atomic orbital and hybrid orbital?
3. How effective is the use of 5C‟s module of instruction in improving students‟ level of understanding on hybridisation of molecules?

It is hoped that the information generated in this study would bring to light the usefulness and the possibilities of 5C‟s module for effective teaching and learning hybridisation. It brings out the benefits that the use of 5C‟s offer students and how to help teachers to effectively and efficiently teach hybridisation to inculcate creative thinking in their pupils. It can also boost the interest of teachers and pupils and foster the creative transfer of abilities of the pupils to other subjects. The study can also serve as reference material for further research into the development of other activities for instruction that may reflect ways and means pupils learn hybridisation.

All I am asking of you is for you to participate in the study and give your views on the subject matter.

Part 2

It is important that you read and understand the following general principles:

1. Participation in the project is completely voluntary and no pressure, however subtle, may be placed on you.
2. It is possible that you may not derive any benefit personally from your participation in the project, although the knowledge that may be gained by means of the project may benefit teachers, students, the school, policy makers, and other researchers.
3. You are free to withdraw from the study at any time, without stating reasons, and you will in no way be harmed by so doing. You may also request that your data no longer be used in the study.
4. You will be given access to your own data upon request.
5. You are encouraged to ask me any question you may have regarding the study and the related procedures at any stage. I will gladly answer your queries.

I, the undersigned ……………………..…………………………… (Name) have read the preceding premises in connection with the study, as explained in Part 1 and Part 2 of this informed consent form, and I declare that I understand it. I was given the opportunity to discuss relevant aspects of the study with the researchers and I hereby declare that I am taking part in the study voluntarily.

Signature: ……………………… Date: ………………………

APPENDIX F

SAMPLE OF STUDENTS' RESPONSES TO QUESTIONNAIRES

This questionnaire is designed to elicit information on how senior high school students' level of understanding on hybridisation molecules can be improve with the use of 5C's module of instruction. This is solely for academic purposes, therefore, all the information you provide will be stored confidentially and securely in accordance with data protection policies. This study is anonymous so you do not need to provide your name. I am therefore asking if you could answer the following questions by ticking in the boxes (√) or writing in the spaces provided where applicable. Thank you.

SECTION A: DEMOGRAPHIC CHARACTERISTICS

1. Gender:

   Male (√) Female ( )

2. Age:

   < 13 years ( ) 14 - 16 years (√) 17 – 19 years ( ) > 20 years ( )

SECTION B: UNDERSTANDING IN HYBRIDISATION OF MOLECULES

3. Which of the following statements best describes the concept of hybridisation?

   Bonding of atomic orbitals to give rise to molecular orbitals ( )

   Combination of two or more ionic substances ( )

   Combination of two or more orbitals to give a stable species ( )

   It is the mixing of atomic orbitals ( )

   It is the mixing of two or more native orbitals to form hybrid orbitals (√)

   Mixing of atomic orbitals of different shapes ( )

Mixing of two or more electrons ( )

Mixing up of two or more atoms ( )

Mixture of atomic orbitals of two or more atoms ( )

Overlapping of atoms to form stable bonds ( )

The paring of more than one atom ( )

4. What are the types of hybridisation that exists in the central atoms of the given species?

SO_2 ___sp²___

SO_3 ___sp³___

SO_4^{2-} ___sp²___

SO_3^{2-} ___sp²___

SECTION C: UNDERSTANDING ON ATOMIC ORBITALS AND HYBRID ORBITALS

5. Which of the following statements best describe the concept of atomic orbitals?

A hollow space; spaces in an element where atoms occupy ( )

Mixing of orbitals ( )

Orbitals of the same energy ( )

Orbitals used in bonding ( )

Orbitals which differ from one state to another ( )

Pathway that atoms trave; ( )

Shells made up of the same kind of atoms ( )

Space around nucleus where there is a high probability of locating electron (✓)

Sub shells of a principal energy level which has the same energy ( )

They are the number of shells ( )

Where electrons can be located ( )

6. Which of the following statements best describe why orbitals undergo hybridisation?

Different orbitals have different energies ( )

Different orbitals have different energy and shape ( )

They contain charged particles ( )

They undergo hybridisation when they bond with other orbitals (✓)

To form a single or multiple bond ( )

To form pi and sigma bonds and their geometry ( )

To form some bond ( )

To give equal energy levels ( )

To know their molecular structure ( )

To obtain inert gas structure or octet rule ( )

To obtain overall stability ( )

7. Which of the following statements best describe why molecular orbital theory being a good model for explaining bonding in the NO molecule?

Because it can have more than one orbital (✓)

Hybrid orbitals only exist when there is to be bonding or mixing of different orbitals for bonding ( )

Isolated atoms do not have bond with any other atoms ( )

It does not mix with its own orbitals ( )

It is single and there is no bond existing ( )

It is unstable difference in energy ( )

It must be stable at ground state ( )

There is no sharing of electrons ( )

8. Which of the following statements best describe difference between hybrid orbital and pure atomic orbital?

Hybrid orbital involves overlapping of orbitals while pure atomic orbitals do not ( )

Hybrid orbitals obey the octet rule but atomic orbitals do not (✓)

Character and energy different from native atomic orbitals so it is more stable ( )

Orientation of their shapes ( )

They contain overlap of two orbitals ( )

They differ in size, shape and energy ( )

Because of their molecular structure ( )

9. What are some of the challenges you encountered during lessons in hybridisation molecules?

I get confused because I do not actually see how the orbitals mix to form hybrid orbitals. We need materials that can be used for illustrations.

SECTION D: USE OF 5C's MODEL IN IMPROVING STUDENTS' LEVEL OF UNDERSTANDING ON HYBRIDISATION OF MOLECULES

10. Indicate by ticking the appropriate level of effectiveness of these two teaching methods in hybridisation molecules.

A. Traditional method

Highly Effective ( )

Very Effective ( )

Effective ( )

Somehow Effective (✓)

Not Effective ( )

B. 5C's model

Highly Effective ( )

Very Effective (✓)

Effective ( )

Somehow Effective ( )

Not Effective ( )

11. Would you say that traditional method of teaching rather than 5C's is a more effective way of learning?

Yes ( )

No (✓)

12. Would you say that traditional method of teaching rather than 5C's is more relevant to your personal development?

Yes ( )

No (✓)

13. To what extent do you agree that participatory and interaction is encouraged in traditional method of teaching and 5C's method of teaching

A. Traditional method of teaching

Very participatory and interactive ( )

Participatory and interactive ( )

Somehow participatory and interactive ( )

Not participatory and interactive (✓)

B. 5C's method of teaching

Very participatory and interactive (✓)

Participatory and interactive ( )

Somehow participatory and interactive ( )

Not participatory and interactive ( )

14. Which of the methods of teaching do you think monitors and give feedbacks on students' mastery of learning?

Traditional Method of Teaching ( )

5C's method of Teaching (✓)

15. In your opinion, which of the methods of teaching motivates students to pursue learning activities and stimulate thinking?

Traditional Method of Teaching ( )

5C's method of Teaching (✓)

16. Tick the appropriate level of satisfaction of the two teaching methods in teaching hybridisation molecules.

A. Traditional Method of Teaching

Very High ( )

High ( )

Low (✓)

Very Low ( )

B. 5C's Method of Teaching

Very High (✓)

High ( )

Low ( )

Very Low ( )

17. Which of the methods of teaching do you prefer in the teaching and learning of hybridisation molecules?

Traditional method ( )

5C's method (✓)

18. Give reasons

Providing us with materials to work in groups help us to learn from each other. We learn from those who are better than us.

We are forced to put ourselves into the learning process when it gets to presentation.

Our doubts are cleared when it gets to the interactive session.

We learn through playing.