UNIVERSITY OF EDUCATION, WINNEBA

IMPROVING STUDENTS' PERFORMANCE IN HYBRIDIZATION AND MOLECULAR SHAPES USING COMPUTERIZED ANIMATIONS AND MODELS

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DECLARATION

Candidate's Declaration

I, GYAMFI COLLINS DESMOND, declare that this Dissertation, with the exception of quotations and references contained in published works which have been identified and duly acknowledged, is entirely my own original work, and that it has not been submitted, either in part or whole, for another degree elsewhere.

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 Dissertation as laid down by the University of Education, Winneba.

Name of Supervisor: Prof. John K. Eminah

Signature: ………………………………

Date: ……………………………………

DEDICATION

I dedicate this work to my caring mother, Miss Grace Assaw, for her tireless effort rendered to me throughout my academic journey.

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LIST OF ABBREVIATIONS

CAM:	Computerized Animations and Models
SHS:	Senior High School
HPT:	Hybridization Performance Test
PIQ-1:	Pre Intervention Questionnaire
PIQ-2:	Post Intervention Questionnaire
VSEPR:	Valence Shell Electron Pair Repulsion
3D and 2D:	Three-dimensional and two-dimensional respectively.

ABSTRACT

This study was designed to improve the students' performance in hybridization and molecular shapes using computerized animations and models (CAM). The target population consisted of the chemistry students of Anlo SHS, however the accessible population comprised of the second-year chemistry students. Purposive sampling technique was used to select one intact class for the study. The main research instrument was test, and supplemented with questionnaire. Students' performance in hybridization and molecular shapes was determined by scores obtained by the students in the Hybridization Performance Tests (HPTs) conducted before and after the intervention. Data relating to difficulties students faced during lessons on hybridization and molecular shapes, as well as students' views on the integration of computerized animation and models were collected using questionnaires. Microsoft Office Excel was used to analyze the data. Descriptive statistics such as mean, percentages, and standard deviations were used to discuss the research findings. Inferential statistics of unpaired samples and paired samples t-tests were used to test the two null hypotheses. The results of the study showed that, the students faced difficulties in hybridization and molecular shapes. In addition, the pre-intervention and post-intervention mean scores were 13.33 and 21.93 respectively, which indicated a significant improvement in students' performance after the intervention. Analysis of the post-intervention test scores revealed mean scores of 23.80 and 20.33 for male students and female students respectively, which indicated a significant difference in mean performance between male and female students. The study recommended that, chemistry teachers of Anlo SHS should integrate CAM in teaching and learning of hybridization and molecular shapes, and training chemistry teachers and students of Anlo SHS on the effective utilization of computerized instructional packages. In addition, educational stakeholders must provide digital resources to enhance effective teaching and learning of chemistry at Anlo SHS.

CHAPTER ONE

INTRODUCTION

1.0 Overview

This chapter contains the background to the study, statement of the problem, the purpose of the study, the research objectives, research questions that guided the study. The chapter also presents null hypotheses that were formulated and tested in the study, the significance of the study, limitations of the study and delimitations of the study, operational definition of terms and organization of the study.

1.1 Background to the Study

As the world is currently dominated by rapid changes in science and technology, today's students grow up with computers. They interact, observe and play with digital devices and their associated technologies. Students therefore spend much time on popular technological platforms such as Facebook, twitter, Instagram and many more. At a glance, these seem to be a waste of time and resources, however, these technologies and social networking, digital games and simulations deserve critical attention (Brobbey, 2012). As these current children grow with computers, it is part of them, and for that matter, a tool they can rely on to learn. These must be used as opportunities to create a very engaging learning environment for effective teaching and learning.

Most developed countries are making very good use of these new technologies to impact the world in many ways. Wells and Lewis (2006) in Owusu et al. (2010) stated that, almost every public school in the United States had access to the internet by 2005. Recently, studies have shown that in UK and USA, the issue is no longer about incorporation of ICTs in courses but rather students' choice for a balance of technology in their courses (Salaway & Caruso, 2008). However, the situation is different in the developing countries like Ghana. Recent educational reforms in Ghana have seen the light of introducing computer literacy into the curriculum of pre-tertiary education (Brobbey, 2012). The author reiterated that, as the country is investing its scanty resources in technology, the computer must be used as a teaching tool with the advancement in the technology.

The language of chemistry and its abstract nature make many students to consider the subject as difficult (Mintzes, 2007). These authors emphasized that despite chemistry teachers make their best efforts to teach, learners do not understand the basic concepts covered in class. Teaching of chemistry must be interesting for learners to experience and accept the content taught. This can be achieved through change in wrong prior knowledge, improvement in performance and change in attitudes. Students' poor performance in chemistry calls for improvement in the teaching and learning of the subject (Aluko, 2008). Despite the importance attached to chemistry as subject matter, there are a lot of gaps between the subject matter and the kind of teaching methods employed by teachers in senior high schools. Based on these, Koomson, Safo-Adu and Antwi (2020) proposed that, the methods employed to teach chemistry in senior high schools need an appraisal. Hybridization and molecular shapes are important chemistry topics which form the foundation of organic chemistry. Relevant knowledge required to understand hybridization include writing of electron configuration and chemical bonding. Analysis of hybridization and molecular shapes under senior high school chemistry curriculum require students to understand atomic orbitals, hybrid orbitals, formation of single and multiple bonds (Calis, 2018). However, hybridization and molecular shapes are very difficult topics for students at all educational levels (Salah & Dumon, 2014). Some findings from previous studies revealed several reasons that account for students' difficulty in understanding hybridization and molecular shapes. Some of the reasons reported are; their abstract nature (Salah & Dumon, 2014), students' misconceptions developed from prior learning experiences (Hanson, Twumasi & Antwi, 2015), teaching strategies employed by teachers (Van der Berg et al., 2011), and students' common-sense reasoning (Talanquer, 2011). As far as individual orbitals, hybrid orbitals formation and their mixing are all microscopic in nature. An effective instructional approach is therefore needed, because the traditional instructional approaches alone are not adequate to present the microscopic nature of chemistry (Koomson, Safo-Adu & Antwi, 2020). Based on these, previous studies such as Hanson, Sam and Antwi (2012), Aidoo et al. (2016) share a common view that, a more effective and engaging teaching strategy should be employed by the teacher. Among these effective teaching methods is the Computerized Animations and Models (CAM) instructional approach. In addition, it is evidenced that teaching methods which do not engage students, motivate and attract their attention will negatively affect students' achievements (Azure, 2015). Ignacio Estrada once said, "if a child can't learn the way we teach, maybe we should teach the way they learn".

A lot of studies (Adherr, Ayiwah & Anyetei, 2019; Akilli, 2021; Duku, 2022) have proposed positive effects of computerized instructional approaches on the performance of low achievers. Therefore, they all recommended the incorporation of computerized instructional packages into teaching and learning. They also found that computerized instructional packages increase students' performance, motivation, attendance, cognitive achievement in the subject, and promote positive attitudes. Asiri (2015) reported that, the use of computerized assisted instruction in teaching chemistry increases students' performance in science processes skills, cognitive abilities, and promote self-directed knowledge construction. Specific earlier studies on hybridization and molecular shapes found that, computerized animations and 3D computerized models enhance students' mental models' construction and conceptual change than those exposed to 2D models in textbooks (Akilli, 2021; Koomson, Safo-Adu & Antwi, 2020; Barak & Hussein-Farajj, 2013). Akilli (2021) reported that, students improved in mental model construction, spatial ability and learning efficiency when 3D computer models were used to teach atomic models. In addition, Teplá, Teplý, and Šmejkal (2022) opined that, 3D models and animations significantly increase students' intrinsic motivation for learning, and significantly improve students in specific areas like engagement, interest, competence, and understanding of the subject matter relevance. Therefore, they recommended the incorporation of computerized animations and 3D models in the teaching and learning of hybridization and molecular geometries. All these literatures discussed earlier have reported positive effects of 3D models and animations, which gave a very strong basics to be used as instructional approach in improving students' performance. Therefore, this study sought to improve the performance of students in hybridization and molecular shapes using computerized animations and models.

Some research studies have also revealed differing findings about the influence of sex differences in chemistry performance in reception to computerized teaching approach. Kibirige and Tsamago (2013) found that the attitudes of males and females towards chemistry were not different when using similar methods. Some studies (Mudasiru & Adedeji, 2010; Mihindo, Wachanga & Anditi, 2017) found no significant difference between the performance of male and female students exposed to computerized instructional approach. Ikwuka and Samuel (2017) reported a significant difference in achievement between male and the female students in favour of the males. Therefore, they concluded in their study that, male students achieve more than female students when taught chemistry concepts with computer animations. On the contrary, Chikendu (2018) found that, female students performed significantly better than their male counterparts when they were exposed to 3D computerized animation instructional approach. Due to differing findings reported by previous studies, this study also sought to investigate if there was any differential effect of computerized animations and models on male and female students' performance in hybridization and molecular shapes.

1.2 Statement of the Problem

The difficulties associated with understanding chemistry have been attributed to a lot of factors such as teaching strategies employed by teachers (Van der Berg et al., 2011), students' misconceptions developed from prior learning experiences (Hanson, Twumasi & Antwi, 2015) and students' common-sense reasoning (Talanquer, 2011). Specifically, many research studies have revealed that students have alternative conceptions about hybridization, molecular geometries, and bond angles (Harrison & Treagust, 2000). According to Salah and Dumon (2014), most studies attributed the difficulty of hybridization and molecular shapes to their abstract nature.

Similarly, the researcher's interaction and experiences with second year chemistry students of Anlo Senior High School revealed that students have difficulties understanding hybridization concepts, molecular shapes and bond angles. Students found it difficult to predict the shapes of molecules, however, they memorized the few common examples used during lessons. Therefore, students found it difficult to predict the correct shapes of other molecules which were not used as examples. Most students did not consider the presence of lone-pairs of electrons in the molecules, and therefore predicted the shapes of NH_3 molecule as trigonal planar. Some also failed to consider the number of substituents around the central atom, so molecules with similar formulae were predicted to have the same shape. Based on these, the researcher developed and administered a test on hybridization and molecular shapes in order to get other direct sources of evidence to support existence of the problem in Anlo SHS. Results from the test revealed several difficulties the students were facing. For example, some students predicted both NH_3 and BF_3 molecules as trigonal planar, about 75% could not describe how sigma and pi bonds are formed. In addition, about 60% predicted the shape of a molecule based on the hybridization state of the molecule's central atom. Therefore, molecules such as CH_4, NH_3, and H_2O with sp^3 hybridized central atoms were all predicted to have tetrahedral shape. All of these evidenced that the students needed an intervention, therefore, this study was designed to utilize Computerized Animations and Models to improve the students' performance in hybridization and molecular shapes.

1.3 Purpose of the Study

The purpose of the study was to improve students' performance in hybridization and molecular shapes using computerized animations and models.

1.4 Research Objectives

Objectives of the study were to:

1. determine the difficulties students faced during lessons on hybridization and molecular shapes.
2. assess the effect of computerized animations and models (CAM) on students' performance in hybridization and molecular shapes.
3. investigate the differences in the mean performances of male and female students after the intervention.

4. find out the views of students on the integration of computerized animations and models in the teaching and learning of hybridization and molecular shapes.

1.5 Research Questions

The study focused on the following research questions:

1. What are the difficulties students faced during lessons on hybridization and molecular shapes?
2. What would be the effect of computerized animations and models (CAM) on students' performance in hybridization and molecular shapes?
3. What is the differential effect of computerized animations and models (CAM) on the male and female students' performance after the intervention?
4. What are the views of students on the integration of CAM in the teaching and learning of hybridization and molecular shapes?

1.6 Null Hypotheses

The following null hypothesis were tested in the study;

Ho2: Computerized animations and models have no significant effect on students' performance in hybridization and molecular shapes.

Ho3: There is no significant difference in the mean performances of male and female students after the intervention.

1.7 Significance of the Study

Useful research must contribute to the volume of existing knowledge to the field under study. In view of this, results of this study would improve students' performance and content knowledge in hybridization and molecular shapes. It would help address some challenges confronting the effective teaching and learning of chemistry at senior high school level. This would serve as a reference document to transform the teaching and learning of chemistry from the traditional method of lecture, discussion, demonstrations and illustration into situation involving innovative approaches. The study also suggests remedies that will make learning chemistry concepts interesting and uncover some benefits teachers and students will accrue from the computer rather than just computer literacy as enshrined in the curriculum. Moreover, little is known about the use of computerized animations and models in Ghana, particularly in teaching chemistry. This study therefore provides evidence on the effects of computerized animations and models in teaching chemistry. It also provides information to the government, Ministry of Education, policy makers, curriculum developers, teachers and other educational stakeholders to incorporate computerized animations and modelling instructional packages to promote the effective teaching and learning of chemistry.

1.8 Delimitations of the Study

The study focused on only second year chemistry students of Anlo Senior High School. This year group was engaged in the study because it was the level the researcher identified the problem, and sought to remediate in order to improve their performance. The topic chosen for the study was only hybridization and molecular shapes. Other SHS chemistry topics were excluded. The animations used in the study were computerized videos animations on hybridization and molecular shapes. The type of models used in the study were three-dimensional (3D) computerized models, and concrete 3D plastic ball-and-stick models.

1.9 Limitations of the Study

The study did not cover a large number of students due to time, accessibility and financial constraints. False information provided by the participants may affect the reliability of the results. In addition, power outages affected smooth usage of the electronic devices which may have affected result of the study.

1.10 Abbreviations and Acronyms

CAM: Computerized Animations and Models

SHS: Senior High School

HPT: Hybridization Performance Test

PIQ-1: Pre Intervention Questionnaire

PIQ-2: Post Intervention Questionnaire

VSEPR: Valence Shell Electron Pair Repulsion

3D and 2D: Three-dimensional and two-dimensional respectively.

1.11 Definition of Terms

Computerized Animations: These are all diagrams, frames or images that are in continuous motion which can be paused, forwarded, rotated or enlarged.

Models: These are 3D computerized diagrams, frames or images that are static. It also comprised concrete 3D plastic ball-and-stick models.

Performance: It refers to the scores obtained by students in a test. A higher score indicates a higher performance and vice-versa.

Senior High School: It is an institution that offers educational content and experiences to students for three years after primary education.

1.12 Organization of the Study Report

This study is organized into five chapters. Chapter One comprised of the background of the study, statement of the problem, purpose of the study, research objectives, research questions, null hypotheses, significance of the study, delimitations of the study, limitations of the study, abbreviations and acronyms, definition of terms used in the study. The second chapter presented a review of the related literature, the theoretical framework, conceptual framework of the study and empirical framework of the study. Chapter Three presented the research design, study area, population, sample and sampling technique, instrumentation, validity of the research instruments, reliability of the research instruments, data collection procedure, pre-intervention activities, implementation of the intervention, post-intervention activities, data analysis and ethical considerations. The chapter Four dealt with presentation of results, analysis and discussion of the study findings. The summary of the findings, conclusion, recommendations as well as suggestions for further studies are presented in chapter Five.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.0 Overview

This chapter deals with the review of the related literature. The review was done under the following sub-headings;

i. Computerized Instructional Packages and Performance
ii. Barriers in Integrating Computerized Instructional Packages in Education
iii. The Use of Models as Teaching Aids in Science
iv. Spatial Ability and Learning with 3D Computerized Models
v. Computerized Animations as Teaching Aids in School Chemistry
vi. Sex and Performance in School Chemistry

Theoretical Framework

i. Constructivism Theory
ii. Conceptual Change Theory
iii. Hybridization and Molecular Shapes

Conceptual Framework

Empirical Studies

i. Effects of Computerized Animations on Students' Performance
ii. Differential Effects of Computerized Instructional Packages on Male and Female Students' Academic Performance.

Summary of Literature Review

2.1 Computerized Instructional Packages and Performance

The rapid development of the world in the field of science and technology has directed interest and research into the use of computerized packages in education. The emergence of the growing need of multimedia in education equally demands a response to the roles of digital technologies in the transfer of knowledge. In responding to all of these, the use of computer is inevitable. According to Jonassen (2000) in Asiri (2015), there are three domains of using computer in education; learning about computer, learning with computer, and learning through computer. Learning about computer has to do with the familiarization of students with computer components and their functions. This domain involves learning about using computers in various ways which develops students' literacy in technology. The teacher only facilitates the process of learning by guiding students familiarize and acquire programming skills related to the computer. Owusu et al. (2010) believe that, this domain deals with how computer is taught as a special subject matter.

Learning with computer involves the design and development of computerized media to enhance students' understanding. This also encompasses teaching and learning with computer instructional packages such as computerized animations, pictures, models, software, and videos that stimulate critical thinking and enhance understanding. With this domain, computers are used as tools to communicate, teach, learn, analyze data, and transfer knowledge. The computer can be used for presentation, data analysis, application packages like SPSS and Excel. Here, students use computers to access the internet in search for information to execute assignments. The use of computers in different forms to make teaching and learning more effective and interesting, such that teachers can now guide students in remote areas which allow for distance learning. There is easy exchange of information between a teacher and large number of students, with computer through the internet. In addition to learning with computers, students write reports, undertake projects like long essays, solve problems, and present reports, while teachers can present learning contents using power point and video conferencing (Owusu et al., 2010).

Lastly, learning through computers makes provisions for transferring information directly from computers to students. The computer acts as a teacher, that provides the subject matter for the students, and progress of students learning are recorded. This includes drill and practice programs which incorporates tutorial, practice and simulation activities (Cotton, 1991). In doing so, the computer can effectively instruct students, assist teaching and learning which enhance understanding.

For many decades, computerized instructional packages have been used for educational purposes in improving students' academic performance. These packages have been captioned in different forms; computer assisted instruction (CAI), computer aided instruction (CAI), computer-based learning (CBL), computer enhanced learning (CEL), multimedia-based learning (MBL), animated instructional learning (AIL), computerized modelling software (CMS), computerized animated package (CAP), animated video learning (AVL), to mention but a few. These computerized packages have been used to teach almost every subject for many purposes, such as improving students' achievement, performance, understanding, determining effect or impact of the particular instructional package on the students' performance.

Allessi and Trollip (2001) opined that; a computerized instructional package is one that is capable for teaching concepts that are challenging or characterized by danger. They reiterated that it is able to present complex and dynamic concepts that are either impossible or difficult to explain using equations, words or experiments. Also, if computerized instructional packages are developed and implemented well, students "love" and achievement in science lessons increase (Lee, 2001). In addition, integration of computerized packages in chemistry lessons can provide an efficient learning environment for students to improve their skills in chemistry by engaging them with "real world" conditions required to make abstract concepts concrete and clear (Mihindo, Wachanga & Anditi, 2017). Similarly, Bhagwan (2005) suggested some merits of computer instructional packages, that they elevate positive effects on students' attitudes, shift instruction from teacher-centered to student-centered, enhance collaborative learning, stimulate teacher-student interaction, promote active learning and provide evaluative learning. In addition, most ideas related to natural phenomenon are accessible with computers, therefore, students are able to visualize such phenomena in a three-dimensional form (Shamai, 2001). Furthermore, Wesi (2011) reported that, computer instructional packages help to eliminate misconceptions among students, build students confidence, help students to conceptualize concepts very well which can be applied further to enhance students' discovery.

Chemistry involves the study of matter and the changes matter undergoes. The processes involved in the changes, behavior of atoms, ions, molecules, and compounds that are generally abstract with theoretical models which are difficult to notice by mere observing, which are solely obtained through mental thinking and visualization (Kennepohl, 2007; Ozmen, 2008). However, a lot of studies have found that computerized instructional packages can significantly improve students' understanding and performance in abstract concepts involving atoms movements, combinations, and their linkages in reality. Some of these studies are elaborated in the next paragraph.

Mudasiru and Adedeji (2010) conducted an experimental study with 120 first year chemistry students sampled from three private secondary schools in Nigeria. The purpose of the study was to ascertain the effect of computerized instruction on secondary school students' performance in biology. The study employed quasi-experimental with 3 × 2 factorial design. Results of the study were analyzed using Analysis of Covariance (ANCOVA). Findings from the study revealed that, students exposed to computerized instruction, either individually or cooperatively significantly performed better than those exposed to conventional regular instruction.

Asiri (2015) examined the impact of computerized instruction on students' acquisition of science processes skills in chemistry. The study comprised 61 grade 11 chemistry students between the ages of 17-18, in Saudi Arabia. Randomized pretest-posttest control group design involving two measurement criteria were used. The measurement criteria were basic science processes skills (BSPS), and integrated science processes skills (ISPS). The experimental group were taught with a computerized designed program, called "Al-Dwalij", whiles the control group were taught with the regular conventional approach. The findings from the study reported that, the computerized instruction increased students' performance on basic science processes skills than those exposed to the conventional approach.

The poor performance of secondary school chemistry students in Kenya prompted Mihindo, Wachanga and Anditi (2017), to conduct an experimental study to reveal much information about the effect of computer-based simulation instruction on chemistry students' achievement. The research design was quasi-experimental involving four non-equivalent control group design. Purposive sampling was used to select four co-educational schools with sample population of 175. Data were collected using Chemistry Achievement Test (CAT), and analyzed using ANOVA. Findings from the study showed that, there was a significant difference in chemistry achievement in favor of those taught through computer-based learning. It was concluded that, computer-based learning improves students understanding of chemistry phenomena and result in higher performance in chemistry.

Julius, Twoli and Maundi (2018) investigated the effect of computer aided instruction on senior secondary students' achievement in chemistry compared with conventional instructional method. The study was conducted with four secondary schools in Nigeria, comprising 174 second-year chemistry students. The four schools were randomly assigned as either a control group or experimental group, with one intact class from each school. The two control groups were taught for six weeks using conventional instructional methods, whereas the two experimental groups were taught using computer aided instruction. The topics treated were; Atomic structure, Periodic table and Chemical families. Data were collected with Chemistry Achievement Test (CAT) and were analyzed using t-test, Analysis of Variance (ANOVA), and Analysis of Covariance (ANCOVA). The findings of their study reported that, students in the two experimental groups exposed to the computer aided instruction significantly performed better than those exposed to the conventional methods.

A study conducted in Ghana by Duku (2022) employed computerized instructional package which was captioned as, "computer assisted instruction", to improve the performance and knowledge retention ability of senior high school students' in integrated science. The study employed an action research approach, where convenient sampling technique was used to select one intact class for the study. The sample population comprised 37 students with 21 males and 16 females. Data of the study was collected with Integrated Science Performance Test (ISPET), and analyzed using dependent sample t-test. The researcher found that, there was a significant improvement in performance after the students were taught with the computerized instruction. It was also reported that, the instructional package significantly enhanced students' retention ability in integrated science.

Nsabayezu et al. (2022) investigated the impact of computer-based simulations on 72 secondary school students learning organic chemistry in Rwanda. Their findings revealed that, the mean marks of students exposed to computer-based simulations were significantly greater than those taught without computer-based simulations. Their study also investigated students' perceptions of organic chemistry after using computer-based simulations in learning organic chemistry units. Their findings reported that, students had positive reflection, motivation and increased level of understanding after using computer-based simulations.

Talan (2021) conducted a meta-analysis on 91 studies conducted by other researchers between 2010-2020 years on the effect of computer simulation techniques on achievement. The research sample consisted of 7575 participants. Data of the study was analyzed using random-effect model. The study reported that, simulation techniques have "broad impact" on students' academic achievement. Several established studies (Brobbey, 2012; Antwi, Anderson & Sakyi, 2015; Kareem, 2015; Adherr, Ayiwah and Anyetei, 2019) on the instructional values of computerized packages in science affirm to its positive impact on students' academic performance. Findings reported by most of these studies indicate how important the use of computerized simulations or instructional packages are capable of improving performance of low achievers. The positive effects of computerized instructional packages as discussed earlier make teaching and learning of science-related contents such as chemistry more interesting and effective compared to the conventional methods. Though computers are not substitute for teachers, they create environment where teachers and students have new innovative and roles in education (Olivera, 2020). Olivera added that, with the computer, the fundamental tasks of teachers are to prepare educational work, correctly implement educational work, motivate students, and facilitate students to acquire knowledge. The use of computerized packages also makes students active participants and very attentive (Geladze, 2015). These evidences also show that computers in teaching and learning are very useful, their usage result in increase in the quality of teaching and learning, broaden students thinking abilities, and reduce teachers' workload. However, computer usage in teaching and learning is largely limited by challenges. The process is very complicated which exposes teachers to a lot of challenges. These challenges are called "barriers". The next paragraph presents barriers associated with integrating computerized instructional packages in education.

2.2 Barriers in Integrating Computerized Instructional Packages in Education

Barriers are conditions that make it difficult for a person or organization to progress or achieve an objective (Schoepp, 2005). In the context of this study, focus is on barriers that prevent schools and teachers from incorporating computerized packages in their activities and instructions. Several scholars in education have classified barriers into two groups; external barriers and internal barriers (Hamutoglu & Basarmak, 2020). Ertmer (1999) described external barriers to include first access, time, support, resources and training, while internal barriers include second access, beliefs, practices and resistance. Hendren (2000) posited that, internal barriers affect instructors, administrators, and individuals, whereas external barriers affect the workplace organization rather than the individual.

Pelgrum (2001) highlighted barriers as material and non-material barriers. He classified lack of computers, and lack of copies of software into material barriers, whereas non-material barriers included lack of ICT knowledge and expertise among instructors, challenges integrating ICT into educational settings, and insufficient teacher time. Hew and Brush (2007) analysis of experimental investigations conducted between 1995 and 2006, classified barriers to include teachers' attitudes and views, institution culture, guiding principles as well as students' knowledge and skills.

In addition, Becta (2004) presented an overview of research done over a ten-year period (1993-2003) in different countries, and proposed two categories of barriers; school level barriers and teacher level barriers. Based on his analysis, school level barriers include insufficient instructional time, lack of resources, hardware, ineffective training, inappropriate organization, poor quality software, and technical problems. Teacher level barriers include insufficient preparation time, lack of confidence, lack of access to ICT resources, resistance to change, no idea of relevance and negative attitudes towards ICT incorporation.

In recent years, barriers have been thought to include a variety of factors classified under primary barriers and secondary barriers (Bingimals, 2018). Primary barriers include lack of equipment, unreliable equipment, lack of technical support, and problems with other resources. Secondary barriers include school-level factors, like institution culture, and teacher-level barriers like beliefs and attitudes about teaching and technology, and openness to new ideas.

According to Dang (2011), the use of ICT tools in lesson preparation is time consuming, therefore, teachers are faced with problems, either during lesson preparation or lesson delivery. The attitudes, views and knowledge of teachers towards digital tools actually influence their acceptance and integration of computers into their teaching process (Jones, 2001). He added that, teachers prefer old conventional approaches to the modern integrated approaches because they lack interest, motivation, acceptance and readiness towards ICT integration. Jones (2001) revealed seven barriers that affect the integration of ICT into instructions. These are; insufficient resources, lack of confidence among teachers, teachers age, lack of individual access in preparing lessons, teaching experiences, lack of training for teachers, and lack of time. An extensive body of research is available to inform us about factors inhibiting teachers in general from using ICT in teaching. Several of this body of research however have studied these inhibitors as single or individual indicators rather than as groups of factors that share a set of common attributes (Ahmad, 2018). Teachers do not have time to design, develop and incorporate technology into teaching contents (Kafyulilo et al., 2017). The study emphasized lack of time as the major barrier to integration of ICT into teaching and learning. Despite the numerous studies on these barriers, there have been no consensus regarding which factor (teacher-related or school-related) is more crucial in impeding science teachers' incorporation of ICT in education. Chen, Tan and Lim (2012) found that external or extrinsic hurdles such as time and curricular restrictions tend to have a bigger impact on teachers' usage of ICT in the classroom than internal or intrinsic barriers. Reja (2016) revealed the following as barriers that are faced in the integration of ICT in education; unavailability of good national and educational policy, high ICT illiteracy of teachers, lack of coordination between ICT policy makers and educational sector, inefficient ICT equipment for training institutions to train teachers in ICT. Talan (2021) meta-analysis of previous studies revealed the following as barriers that hinder the integration of computerized packages in education. These are cost of designing software, difficulty in designing software, lack of time for software development, lack of the ability to select models that are appropriate representations of the reality.

Some findings (Ageel, 2011; Ozen, 2012) share a common view that school related factors are the major factors impeding ICT incorporation. On the contrary, other studies (Becta, 2004; Gomes, 2005) are of the view that teacher-related factors are the major contributing factor. This lack of consensus by previous findings indicates that ICT utilization barriers are context and culture-specific, and are often influenced by personal, sociocultural and system variables such as local policies, subjective norm, prior experience and institutional support (Ahmad, 2018). In light of these, several studies have suggested solutions to deal with the barriers to ICT integration. Stojanovic et al. (2017) opined that most educational institutions still lack computers, laptops, projectors and interactive whiteboards. Their study further revealed that, external barriers can be eliminated with the help of material resources. Olivera (2020) conducted a study survey with five research questions on barriers to using computers in teaching, and how to eliminate them from the teaching and learning environment. Findings showed that, the key barriers to the use of computers are technical equipment and support, and therefore the use of computers in teaching become limited. Olivera (2020) suggested that, as most teachers feel comfortable in their old familiar forms and methods of teaching, continuous training and seminars which break prejudices and fear of computer usage must be organized for teachers. If teachers are well informed of the importance, efficiency, and become aware that multimedia is a means to make complex concepts simple, they will resort to incorporating them into their instructions. Olivera (2020) concluded that to eliminate barriers, seminars and practical courses about computers must be organized for teachers. In fact, these problems are context-based, and must be eliminated in order to obtain the expected effects of computerized instructional packages.

In the context of Ghana, efforts to ensure the implementation of incorporating ICT and computerized instructional packages into Ghana Education is ongoing. These efforts aim at "transforming the Ghana pre-tertiary education from the traditional way into a digital age learning culture, where students will become leaders who can create, promote and sustain a dynamic, technological age learning culture that provides a relevant and engaging education for all" (National Council for Curriculum and Assessment, 2018, p.7). Some efforts that respond to this aim include the distribution of laptops to all pre-tertiary teachers, and organization of Continuous Professional Development (CPD) for all pre-tertiary teachers. Though there were few challenges, by the end of 2022, a significant number of pre-tertiary teachers had their laptops in which the researcher was a beneficiary. The continuous professional development for pre-tertiary teachers has also started across the country. Teachers with certificate, diploma or degree in education have been licensed by the National Teaching Council (NTC). To renew the license, it is expected that, the teacher attends a certain number of workshops which focus on continuous professional development of Ghanaian teachers. All of these attempts by education stakeholders aim at minimizing most of the barriers associated with incorporating digital tools and computerized instructional packages in the teaching and learning process.

2.3 The Use of Models as Teaching Aids in Science

Models are frequently employed in science as representations of objects, processes, or systems (Gilbert & Boulter, 1998). In both research and education, modeling and simulations are used to describe, clarify, and investigate events, processes, and abstract concepts. According to Valanides and Angeli (2008), when an object or phenomena is too big, little, complex, far away, or inaccessible, models are created to represent them. Since models and modeling software are crucial to technology and the essence of science, they are significant in the field of science (Bekiroglu-Ogan, 2006). This implies that, the use of models in science is inevitable in this modern century.

Gilbert and Boulter (1998) classified models into target systems, mental models, expressed models, consensus models, and teaching models. Since models create mental picture in the minds of its audience, the type of model selected has an effect on the mental picture that the student creates. Gobert and Buckley (2000) also classified models into two; mental models and expressed models. They added that, mental models are how people describe their explanatory processes. This type of model is also called internal model. Other researchers also defined mental models as; people's internal simulations of actual events that they employ to comprehend and interpret what occurs (Franco & Colinvaux, 2000), cognitive representations that are unique to the observer (Coll & Treagust, 2003). According to Greca and Moreira (2000), the primary function of mental model is to enable their creators to describe and forecast the system they represent. They further revealed that, the idea underpinning computer models is that mental representations of systems or mechanisms can be thought of as feasible causal models for the system or mechanism they represent and as a mental simulation of the true situation of the problem.

On the other hand, the external representations of internal models are called expressed models. These models are also known as external models, which can be diagrammatic, physical or computational models such as 3D computer models, simulations or animations (Kim & Lee, 2013). Typical hands-on models are the ball and stick models derived from polystyrene spheres and plastic straws, which are just enlarged versions of the molecules they are meant to portray. They are just analogue models used to represent abstract concepts, which are however associated with a lot of limitations (Barnea & Dori, 2000). Some of the limitations include; all straws are equal, meanwhile bond lengths are not equal. Barnea and Dori (2000) opined that, teachers frequently utilize one kind of model, which limits students' exposure to models and leads to poor or incomplete model perceptions on their part. Computer modelling is regarded as a crucial step in the teaching and learning of science. Due to this, more practice using models as intellectual tools that present different conceptual views of phenomena and explanations of the functions of models in support of scientific inquiry are needed for students (Jay & Smith, 1991). This implies that teachers' perspectives are crucial because they may not be able to adequately incorporate models into their teaching if they lack the requisite grasp of the nature and function in the development of a field (Gilbert & Boulter, 1998; Barnea & Dori, 1996).

In Mayer (2003), Mayer's cognitive theory of multimedia learning revealed some reasons for the effectiveness of models like 3D models as learning tools. His theory was based on three assumptions; dual channel assumption, limited capacity assumption, and active processing assumption. Mayer's dual channel assumption proposed that, information presentation and processing in humans is cognitively linked to two sub-systems; verbal and visual materials. This assumption is built on Paivio dual coding theory, which proposed the use of both verbal and non-verbal codes (Moreno & Valdez, 2005). Based on this assumption, Mayer (2003) stated that, the construction of mental representations using text and images are recognized by using multimedia, and that students can learn sufficiently from multimedia than conventional presentations with only words. According to Mayer and Moreno (2003), the limited capacity assumption is of the view that, the working memory channel can build a limited amount of visual or non-visual information at a given time. This assumption is in agreement with Baddeley's working memory model and Sweller's cognitive load theory (Paas et al., 2003). Lastly, the active processing assumption assumes that students become aware of the necessary information, select, and organize the information into coherent mental models, and integrate the models into prior knowledge (Urhahne, Nick & Schanze, 2009). This implies that, processing within verbal and visual channels lead to meaningful learning. According to Akpan (2001), models like 3D computerized models in science classrooms significantly improve learning achievements which were impossible with the traditional approaches.

Students encounter a lot of difficulties when learning science subjects like chemistry, as most chemistry concepts are abstract, they expose students to create plethora of misconceptions and mental models which affect their scientific development (Chen et al., 2015). One common and effective solution to this problem is the integration of visualization tools like computer models (Barak & Hussein-Farraj, 2013). Some important reasons for integrating computer models include; enhance better understanding, serve as effective communication tools for science concept (Ametller & Pinto, 2002), provision of knowledge that are unavailable with the sole use of verbal explanations (Patrick, Carter & Wiebe, 2005). In addition, they enhance visual explanations of invisible scientific phenomena (Gobert & Buckley, 2000), provide effective learning experiences that links phenomena to reality (Kim & Lee, 2013). Furthermore, they provide innovative circumstances which allow students to enrich their understanding of invisible abstract concepts (Barak & Hussein-Farraj, 2013). Models as instructional aides have proven to improve the conceptual understanding and performance of students compared to the regular classroom methods. The following paragraph presents findings reported by some studies on the use of models in chemistry.

Sarpong (2015) investigated the impact of using visuo-spatial models as instructional aids for teaching molecular and hybridization geometries with associated bond angles. The study was conducted at St. Joseph College of Education in Ghana. It involved two cohorts; experimental and control groups. Pre-intervention test administered to the two groups produced the same mean score of 22.63, which showed that both groups exhibited similar conceptual understanding before the intervention. During the intervention, the experimental group was instructed using visuo-spatial model teaching approach, whereas the control group was instructed using conventional teaching approach. A post-intervention test was conducted for both groups, results showed that, the mean scores of the experimental group and the control group were 77.55 and 36.92 respectively. This represented a significant difference in performance in favour of the group exposed to the visuo-spatial models. In addition, the study reported that, lecture method, involving pamphlet explanations was the only method employed by the college tutors in teaching hybridization and molecular geometries, which posed a lot of challenges for students to understand. It was also revealed that, the use of visuo- spatial models as instructional approach significantly improved students' argumentative skills and performance, developed their spatial thinking ability and higher thinking skills, and encouraged a positive competition among the students.

Koomson, Safo-Adu and Antwi (2020) conducted a quasi-experimental study with 129 senior high school students in Ghana. The study focused on investigating the effect of computer simulation and computerized modelling software in teaching and learning hybridization. The 129 students were categorized into two groups; control and experimental groups, and taught for two weeks. The control group was taught with traditional teaching approach whereas the experimental group was taught using computer simulation and modelling software. Findings from the study indicated significant difference in performance in favour of the experimental group. They also found that, considering the experimental group, students in cooperative group outperformed those in individualized context. This indicates that computerized simulation and modelling software was more effective compared to the traditional approach, and even most effective in cooperative setting. Based on these findings, they recommended the incorporation of computer simulation and modelling software in the teaching and learning of hybridization, in a cooperative context.

Erlina, Enawaty and Rasmawan (2021) employed simple molecular model to enhance students understanding of molecular geometry based on valence shell electron-pair repulsion (VSEPR) theory. The study comprised 54 first year students offering chemistry education at Tanjungpura University, Pontianak. One-group pre-test post-test design was used in the study, with conceptual test as the research instrument; administered before and after learning with simple molecular models. Results of the study were analyzed using dependent sample t-test with SPSS. Findings from the data analysis showed a significant improvement in the post-test results compared to the pre-test results. This implied that, the simple molecular model significantly enhanced the students' understanding of molecular geometry.

Rahmawati, Dianhar and Arifin (2021) also analyzed the spatial ability of students using 3D virtual representation on the topic "molecular geometry". The study was conducted with 13 males and 23 females of year 10 secondary school students in Indonesia. The problems that prompted this study were students' difficulty understanding abstract concepts in chemistry, and the low spatial ability in visualizing interactions at the sub-microscopic level in chemistry. Research tools used for collecting data were prior knowledge quiz, spatial assessment, students' worksheets, interviews, observation worksheets, molecular geometry test and reflective journals. The stages involved three phases; engage, explore and explain. The study revealed that, though the students' ability in spatial orientation was low after learning with the package, abilities involving mental manipulation and rotation of 2D or 3D objects developed significantly. This approach was applied successfully by the students to enhance their conceptual understanding of molecular geometry. These literatures suggest that, models as teaching aids are very important in chemistry which help both teachers and students, and must be incorporated in the teaching and learning of chemistry.

2.4 Spatial Ability and Learning with 3D Computerized Models

According to Lohman (1993), the capacity to create, store, retrieve, and modify coherent visual pictures is known as spatial ability. Barnea (2000) as cited in Akilli (2021), is of the view that, when objects are presented in two dimensions, spatial ability entails the capacity of expressing, rotating, and inverting them in three dimensions. This entails imagining the changes when objects are rotated from one dimension to another. Since most chemistry phenomena are more abstract, spatial ability is very important in the chemistry discipline. According to Black (2005), spatial ability is a cognitive component that is associated with high achievement in science. Therefore, brain functions for information processing are involved in spatial skills which allow for the translation of abstract visualization into a concrete object (Orde, 1997). Furthermore, Harle and Towns (2011) defined spatial ability as the ability to create, maintain and effectively manipulate visual images. Lohman (1993) grouped spatial ability into three aspects; spatial orientation, spatial relation, and spatial visualization. Harle and Towns (2011) defined spatial orientation as the ability to view objects from different perspectives. Spatial relation is the ability to rotate 2D and 3D images through cognitive operations (Gabel, Briner & Haines, 1992 cited in Rahmawati, Dianhar & Arifin, 2021). Lastly, spatial visualization is the ability to go through multiple spatial transformations like rotating, manipulation and reflection of complex objects than spatial relationship and spatial orientation (Harle & Towns, 2011). It is believed that, these three aspects are very crucial in understanding hybridization and molecular shapes. Several studies as presented in the next paragraph have confirmed that 3D computerized models significantly improve students' spatial ability and mental model construction.

The Purdue Rotation and Visualization Test by Bodner and Guay (1997), studied the relationship between spatial ability and students' performance in chemistry. They reported that, it improved students' cognitive abilities in higher spatial topics in chemistry. Rahmawati, Dianhar and Arifin (2021) employed the Purdue Rotation and Visualization Test to analyze students' spatial ability of molecular geometry using 3D virtual representations. In their study, they categorized spatial abilities into three aspects, as proposed by Lohman (1993); spatial orientation, spatial relation and spatial visualization. Their findings reported on a spatial test comprising of the three spatial aspects showed that, spatial relation ranked highest with a percentage of 77.94%, followed by spatial visualization with 63.26%, and the least performance was observed on spatial orientation to be 53.50%. The significant performance in spatial ability indicated that, students were able to imagine the rotation of 2D and 3D objects through cognitive structures, which was also reported by Bodner and Guay study in 1997.

Akilli (2021) examined the effectiveness of three-dimensional (3D) computerized models on undergraduate student-teachers academic achievement, mental model construction, and spatial ability on atomic models. Random sampling technique was used to sample 61 students into two groups; treatment group and control group. The treatment group was taught with 3D computer models whereas the control group was taught with traditional teaching approach. Independent sample t-test statistics was used to determine the significant difference between the two groups, whereas Cohen's d and eta-squared values were calculated to ascertain the effects of the computer models. Findings from the study showed that, instruction involving 3D computer models significantly increases students' achievement and mental model construction. In addition, analysis of Purdue Visualization of Rotation Test (ROT) showed that, spatial ability performance of the treatment group significantly improved compared to their counterparts in the control group. This indicated that computerized 3D models effectively enhanced students' spatial ability. Furthermore, Cohen's d was determined to be 1.16, indicating that, 3D computer models had significant large effects on the students' spatial ability. A lot of studies (Wang, Chang, & Li, 2007; Williamson & Jose, 2008) have also reported that, 3D computerized models significantly improve students' spatial abilities which are very important in understanding spatial concepts like hybridization and molecular shapes.

2.5 Computerized Animation as Teaching Aids in School Chemistry

Today, scientific education in schools use a variety of techniques and instructional tools. In teaching chemistry, teachers use still images such as charts, maps, printed graphics, 2D and 3D models, working models, audio and visual tapes, or CDs (Kirty, 2008). One accepted method of delivering information in visual form is through graphics. Graphs, maps, and charts have all been depicted using graphics. By illustrating something that would require numerous words to describe, the use of graphics may help save words. Science learning was found to benefit more from carefully crafted images than from text alone (Kirty, 2008). However, due to the numerous movements and motions involving complex structures and systems, such as the process of hybridization, atomic structure, breathing, blood circulation in various species, and machine operation, it becomes difficult to understand adequately through still images alone. Only few students are able to correctly visualize the processes. Another accepted method of delivering chemistry is through practical work, which according to Kirty (2008), work that requires students to see or manipulate real objects for themselves (individually or in small groups) or by observing teacher demonstrations is referred to as practical work. The researcher added that, though doing practical work helps students learn science, it is impractical to work on some scientific-related issues in the school laboratory because doing so maybe expensive, risky, unethical, unsafe or tiresome. For instance, it would be very dangerous working with radioactive substances in ordinary laboratory. Furthermore, by executing chemical reactions, it is challenging to describe the stereochemistry of a molecule or the process of a chemical reaction. Practical activities in the laboratory become limited in all these aspects, and hence require the use of a more effective and safer tools like computerized video animations.

The employment of computerized animations as teaching tool can fix most of these difficulties. Animations are considered as forms of visual information. Computer animation is a computer-generated series of images, frames, or graphics that depict the states or positions of a specific item at various time intervals (Patete & Marquez 2022). According to Gambari, Falode and Adegbenro (2014), there are two modes of illustrating animations; static and animated. Static illustration consists of graphics showing the scientific phenomenon without visual movement of the processes. Animated illustrations display the process with visual movement to show the operational process. Paivio's dual coding theory identified two separate information processing systems; visual system and verbal system (Gambari, Falode & Adegbenro, 2014). Animation involving the combination of visual and verbal knowledge stores information in the long-term memory, thereby enhancing encoding and information retrieval (Riber, 1994). In addition, Kearsley (2002) revealed that animation facilitate students' encoding process than static visuals, this makes retrieval of information from the long-term memory into the short-term memory very fast and efficient. The major benefit of animation is that, everything can practically be animated using 2D or 3D animation software, including complex movements like the rotation of an atom's electrons. Kirty (2008) opined that, with animation, any object or phenomenon can be observed from the necessary angle. There is no language barrier, thus it may work for all students, including those who are smart or dull. The past two decades has seen a boom in computer animation usage because of technological advancements in computer science. There are a lot of reasons behind the extra-ordinarily demand in the use of computer animations such as limitations, restrictions, costs, or lack of such objects in reality. A growing role for animations in teaching has emerged in recent years and computer animations have always been used to improve learning effects, particularly when students are dealing with abstract concepts.

Based on techniques used in creating animations, they can be categorized into traditional animations, stop-motion animations, computer animations and mechanical animations (Chikendu, 2018). He added that traditional animations were employed in the 20th century for animated films, where individual frames were photographs of drawings, and each drawing differs from each other to create illusion of movement. These drawings are then photocopied into transparent acetate sheets. The traditional animations became archaic in the 21st century. Stop-motion animations consist of animations which deals with physical manipulation of concrete objects, which are captured into frames of films to create continuous movements. Examples of stop animations include clay animation, model animation, puppet animation, cut-out animation, and object animation (Chikendu, 2018). The author further explained that, clay animations use figures made from clay to create continuous motions, cut-out animations are animations created by movements of two-dimensional pieces of materials. Object animations are those which involve the use of non-living objects in stop-motion animations. Model animations are animations created to interact with real world objects. Puppet animations comprised non-stop motion of puppet figures that are interactive in a constructive environment. Computer animation refers to series of images, which appear in a continuous manner, that are synchronized into one effect (Dziedzic, 2015). The sole determinant is that, the combination of images is done with a computer. Mechanical animation makes use of mechatronics to create machines in a form of robotic animations (Chikendu, 2018).

According to Liu and Elms (2019), animations usage serves two main purposes or uses; explanation of basic concepts, provision of real-world context and application of existing knowledge. With the first use of animations, some studies (Kelly & Jones, 2007; Nelson et al., 2017) have employed black and white animated graphics to illustrate the abstract movement at the molecular level. Nelson et al. (2017) employed animated simulations to explain electron movements during the process of diffusion. Also, Kelly and Jones (2007) employed animations of molecular structure and dynamics to enhance students' understanding of abstract ideas in chemistry. In their study, they investigated how the features of two different molecular level animation styles affect students' explanations of sodium chloride dissolution in water. They found that, explanations given by students after watching the video animations significantly improved, however, some students' prior misconceptions retained, and new misconceptions showed up. The second use of animations which deals with the provision of real-world context and applications have also been employed in several studies (Adam et al., 2017; Bassford et al., 2016; Mather, 2015). Bassford et al. (2016) employed realistic interactive crime setting into science, technology, engineering and mathematics (STEM) courses to help attract students into interactive learning. Mather (2015) used animated virtual landscape that allows students to interact with robots in a programing task, which significantly had a positive effect on the students' achievements.

There are numerous abstract ideas in chemistry that call for complicated concepts, many of which are not immediately useful outside of the classroom (Stieff & Wilensky, 2003). According to Nakhleh (1992), the abstract nature of chemistry contributes to students' misconceptions. Students' ideas that are different from scientific ideas are captioned variously as misconceptions, alternative conceptions, and alternative frameworks (Ozmen, Demircioglu, & Gokhan, 2009). Previous studies (Johnstone, 1993; Raviola, 2001; Ozmen, Ayas & Costu, 2002) share a common view that chemistry knowledge is represented by scientists at three levels. These are the macroscopic, the sub-microscopic and the symbolic levels. The senior high school syllabus expects students to understand hybridization of atomic orbitals, describe the formation of hybrid orbitals (sp, sp^2, sp^3), describe how sigma and pi-bonds are formed, and illustrate shapes of molecular compounds (CRDD, 2010, p.10). A careful examination of these concepts shows how difficult it is to visualize how atoms and molecules interact at a sub-microscopic level, and therefore call for representations like models, symbols, diagrams, and animations. Despite the increasing emergence of cartoon programs in education, there is limited research on the use of animations as instructional media in higher education (Adam et al., 2017; Kelly & Jones, 2007).

Sangar and Greenbowe (1997) reviewed several studies on the importance of computerized animations in chemistry instruction. They found in several studies that students have considerable difficulties answering conceptual questions based on particulate nature of matter. They also found three theories proposed for computer animation and learning; Piaget theory of intellectual development, Paivio dual coding theory, and Mayer and co-workers dual coding theory (contiguity theory). Paivio dual coding as discussed earlier assumes that learners store information received in working memory as either verbal or visual mental representations in long term storage. Piaget theory of intellectual development focus on the process by which learners develop logical reasoning abilities. The contiguity theory assumes that when pictures and words are presented simultaneously, they are more effective than presented separately (Kirty, 2008). Based on these, Sanger and Greenbowe concluded that instructions which involve the incorporation of molecular level computerized animations have significant positive effects on students' conceptual understanding of processes.

2.6 Sex and Performance in School Chemistry

Academic performance helps educational institutions determine the effectiveness of an educational curriculum on students. According to Arshad, Zaidi and Mahmood (2015), academic performance indicates the extent to which teachers and students have accomplished their educational goals and objectives. The researchers emphasized that, a good representation of educational goals achieved within a period can generally be determined by performance. Differences in sex factor has been overlooked in several studies, but differences in performance between males and females have attracted a lot of attention now (Hung, Yoong & Brown, 2012). So far as the world continues to be globalized, attention shifts towards investing into Science, Technology, Engineering and Mathematics (STEM). In order to realize this, every member; males and females must participate in STEM activities (Adekunle et al., 2021). The researchers stated that, educators in science have recognized this performance gap between males and females in chemistry, and have focused on designing interventions and treatments to bridge this gap. According to Ansalone (2009), several studies continue to report that differences in students' sex are related to their achievement in science disciplines. The gap in differences in sex performances have been attributed to factors such as, roots from the homes, and perception of the population about males and females (Nzewi, 2020).

Kelly (1981) reported that, teacher characteristics and teaching styles contributed to differences in performance between males and females. Males were better served by the way science was taught in schools than females. Females' conceptual growth was constrained to passive information reception, whereas males' conceptual growth was promoted to be a wider inquiring approach. This made science-related contents fit well in the learning styles of males than females. In addition, science teachers connect with females less efficiently than they do with males. According to Kotte (1992), mathematical ability is strongly related to science achievement. Therefore, as females generally have low mathematical abilities, it made them lack interest in science subjects like chemistry and physics that involve mathematical contents.

Olagunju (2001, p. 19) reported the following reasons for the differences in sex performance;

i. Teachers handle females differently from males in terms of instructional strategy and expectations.

ii. Males' command greater attention from teachers which make them participate more actively in class activities.

iii. Both within and beyond the classroom, there are disparities that prevent females from having access to certain subjects and range of interests.

iv. Male science instructors and professionals usually served as role models for males than for females.

v. Inherent cultural barriers and genetic variations inhibit girls' participation in lessons.

vi. Females often displayed lower self-esteem and less confidence in their scientific abilities.

Olagunju further explained that, the culture restriction on what people can do has created a pattern of dominance and submission of females to males, which restricts female students' participation in science activities. The biological imbalance caused by fluctuating hormonal secretions and psychological shifts is the focus of the genetic variations. Despite the hereditary problem, females are not less capable in sciences.

Haertel et al. (1981) in Busolo (2010), was of the view that, spatial ability and visualization are the major causes of the differential performance between males and females in science, and for that matter chemistry. They reported that, males have a relatively higher spatial abilities that give them an advantage over females in the study of science-related contents. Females exhibit weak skills on science contents involving spatial abilities, such as geometries, angles, rotation motions and graphical skills. Busolo (2010) further stated that, chemistry demands revision and practice, meanwhile most household activities are reserved for females. Since there is unequal participation of males and females in home activities, it serves as an obstacle for females to get enough time for revision and practice. The resulting effects of these obstacles and mindsets contribute to the less achievement and participation of females in science contents like chemistry. Therefore, he classified students' sex as a factor that influence students' performance in chemistry.

Ajaja (2012) designed an Ex-post facto study to investigate 637 undergraduate students of biology, chemistry and physics education. The findings revealed that; biology enrollment was dominated by females, physics enrollment was dominated by males, and nearly equal enrollments of males and females in chemistry. In terms of performance, male students significantly performed better than the female students on grade points in chemistry and physics. However, there was no significant difference in performance between males and females in biology. This implies that, areas where females are well represented, enrollment is related to their performance as observed in the case of biology. In terms of high ability in chemistry and physics, no significant difference was observed between males and females. Meanwhile, a significant difference was found in terms of middle and low abilities in chemistry and physics. It was argued and reported in the past that females exhibit some inherent characteristics which limited their capacity to learn scientific skills (Ajaja, 2012). The under-representation of females, and their low performance have also been attributed to the perception of less opportunities available for them in the science fields (Ansalone, 2009).

Ezeudu and Obi-Theresa (2013) investigated the effects of sex differences and location on chemistry students' achievement, in Nigeria. They found that, the male students highly performed better than their female counterparts. Similar result was obtained in Ethiopia by Tenaw (2013) who reported that male students outperformed the female students in chemistry study which involved 100 students. The study attributed the lower performance of female students to lack of fundamental study skills, and difficulty in handling materials needed in examinations. Ekine and Abay

(2016) highlighted few extrinsic factors that contribute to females' negative attitudes, beliefs and perceptions about science, particularly chemistry education. They include classroom practices, curriculum design, teachers' attitude, teacher-student and peer interactions, pedagogy and assessment methods, and the overall school environment.

Irakoze, Gakuba and Karegeya (2021) did a survey to assess the effect of gender perspective towards chemistry in three secondary schools comprising 257 participants in Rwanda. They reported a slight difference between males and females in terms of attitude, beliefs and perceptions towards chemistry, however, the slight difference was in favour of the males. They further reported some factors underpinning the low performance of females. These are; low confidence among female students, poor teaching methods, and insufficient female role models.

In Ghana, there have been a concern about under representation of females in science and mathematics related programme. Comparatively, males are well represented and generally outperform the females in these areas. Several studies conducted in Ghana reported males outperformed their female counterparts (Oppong, 2011; Armah, Akayuure & Armah, 2021). Most of these findings have played a significant role, in serving as foundation to pay attention to female inclusion in the under-represented areas in tertiary institutions. For example, some programs which were often male-dominated like chemistry, engineering, mining programs, medicine, physics have now seen improvement in females' representation. Efforts targeted at achieving this include the reduced cutoff points by some tertiary institutions, and provision of scholarships for females that venture into these fields. Wrigley-Asante, Ackah, and Frimpong (2022) recently conducted a comparative study in Ghana, by comparing the academic performance of males and females at the university level with that at the senior high school level studying STEM subjects. It was reported that, the performance of male students was better than female students at the senior high school level, particularly in chemistry and physics. However, there was an improvement in females' performance at the tertiary level compared to their male counterparts. Factors reported to influence such difference in academic performance at the senior high level include gender stereotypes, teaching approaches, lack of motivation and parental support. It was emphasized that, gender stereotypes highly contributed to the difference in performance at the senior high level. On the contrary, the improvement in females' academic performance at the tertiary level was attributed to advocacy campaigns on women's empowerment. On the other hand, the decline in males' academic performance at the tertiary level was also attributed to factors such as engagement in extra-curricular activities and economic businesses. Results of their study was in line with findings reported by Ajaja (2012). His study on differential performance of males and females in science reported inherent influences caused by cultural, societal, school effect, teacher effects, nature of science, and attitudes to science as the contributing factors responsible for the difference in performance. All of these evidences show that, students' sex is an important factor that influence students' performance in chemistry at all educational levels.

2.7 Theoretical Framework

Theoretical framework of a study is the structure that supports the basis of the study. With theory, ideas can be generalized about observations comprising interrelated set of ideas (Atta, 2015). Effective and pedagogical meaningful educational activities need the use of learning theories. Clarity, focus and direction are provided by a learning theory during an instructional design (Yilmaz, 2008). Hence, a framework for effective instruction should consider the theoretical foundations upon which it is built (McLoed, 2003). This study was supported by the constructivism and conceptual change learning theories.

2.7.1 Constructivism learning theory

According to Yilmaz (2008), the eighteenth-century philosophers; Vico and Kant are the first known sources of constructivism. Constructivist pedagogy, which has its roots in cognitive science is particularly informed by the ideas of John Dewey and William James, as well as Jean Piaget's work with the sociohistorical writings of Lev Vygotsky, Jerome Brunner, and Ernst von Glasersfeld, to mention a few.

Constructivism is a philosophy that emerged as a result of opposition to conventional western notions of knowledge. Therefore, it stands in stark opposition to positivism and objectivist epistemology (Hendry, Frommer & Walker, 1999). According to this theory, individuals construct knowledge and meaning based on prior learning experiences (Dewey, 1938; Bruner, 1960). The theory considers learning as an active process of constructing new knowledge, where individuals base on prior experiences to build their own knowledge and understanding of the world. Hendry, Frommer and Walker (1999) stated that, constructivism views that knowledge cannot exist outside of our minds, truth is not absolute, and knowledge is created by individuals based on experience rather than being discovered. This is in contrast to the objectivist idea of truth and meaning inherent in objects, which does not depend on any consciousness. According to Brooks and Brooks (1999), constructivism is premised on construction of individuals own understanding of the world based on reflection on prior experiences. In addition, constructivists are of the view that, people build knowledge by making meaning of their experiential realities rather than passively absorbing information from the outside world or authoritative sources (Maclellan & Soden, 2004). Therefore, it assumes that, the learners play an active role in building new knowledge for themselves, and teachers must focus on the use of constructivist pedagogy. Richardson (2003) as cited in Yilmaz (2008) explained constructivist pedagogy as the development of learning environments, activities and methods in the classroom that are based on a constructivist theory of learning. He added that, this pedagogy centers on helping each student develop in-depth knowledge of their chosen subject and learning habits that will benefit them in future. It is believed that as learners construct meaning, they learn along. This implies that learners must be the center of the learning process. According to Maclellan and Soden (2004), this theory of meaning construction from previously acquired knowledge implies that;

I. learners are not passive recipients of knowledge, but rather intellectually productive beings.
II. the main focus of instruction should be on helping students think.
III. the dialogue that is facilitated by both teachers and students serves as the source of intellectual authority rather than either the teacher or the materials.

According to Richardson (2003) in Yilmaz (2008), numerous theorists and scholars categorize all forms of constructivism into three; sociological, psychological and radical constructivism. The epistemological premise underlying all the three categories is that knowledge or meaning is not discovered but created by the human intellect.

2.7.1.1 Principles of constructivism

Constructivism does not impose strict guidelines for creating a learning environment; it is rather descriptive than prescriptive (Wasson, 1996). The constructivist theory of learning is comparable to cognitive learning theories in a number of ways since it emerged from cognitivism. The idea that “knowledge does not and cannot have the objective of constructing an independent reality, but instead it has an adaptive function" distinguishes constructivism from cognitivism (Wasson, 1996).

Yilmaz (2008, p.164), presented a summary of the principles and assumptions of constructivists view of learning as follows;

1. Learning is an active process
2. Learning is an adaptive activity
3. Learning is aided by social interaction
4. The context in which learning takes place is where it is based.
5. Knowledge is created by the learner and is neither innate, passively absorbed nor invented.
6. Every piece of knowledge is unique and subjective
7. Every knowledge is socially constructed
8. Making sense of the world is fundamentally what learning is all about
9. Learning is influenced by previous knowledge and experience.
10. Meaningful, open-ended, critical challenges are necessary for effective learning.

According to Fosnot (1996), constructivist instruction rejects the notion that symbols or concepts can be broken down into distinct elements and taught outside of their context. Instead, constructivist teaching gives students' meaningful practical experiences that allow them to spot patterns, develop their own hypotheses, and organize their own models, concepts, and approaches. The classroom transforms into a micro-society where students participate in activities, conversations, and reflections together and therefore instead of dictating autocratically, teachers facilitate and guide. Based on these, Fosnot (1996) proposed a constructivism model which display the interconnection among the individual learner, surrounding people, and medium of interpretation, as shown in Figure 1.

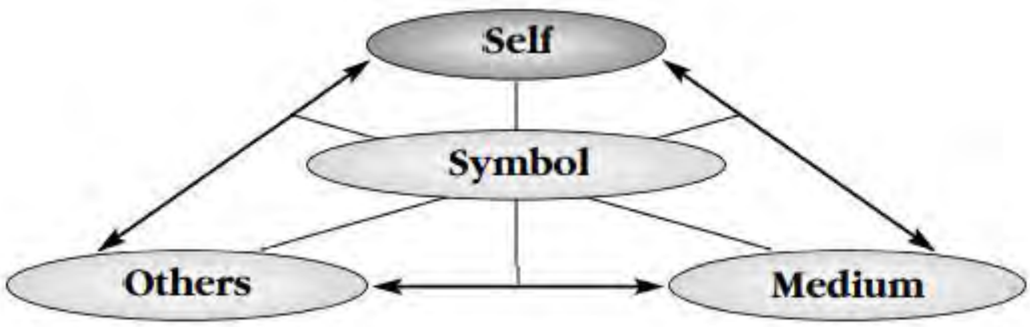

Figure 1: Constructivism learning model proposed by Fosnot (1996)

In line with the present study, experience learners obtain during the use of computerized animations and models during teaching and learning provided them with the medium, context and perfect experience to construct their own understanding. This is because, during the use of computerized animations and models, students were provided with real experiences, analogies, models and video animations that promote exploration and construction of their own understanding. Learners could make sense of these experiences accrued from the experiences in the class to construct meaningful knowledge at their own pace. In addition, the present study, provided interesting video animations and models during the intervention that allowed learners to conceptualize and explore beyond what is given in the classroom. These models created plethora of links for the learners to interpret individually and socially, learn at their own pace and create knowledge for themselves. The constructivism is of the view that, the most relevant role of teachers in teaching science is to serve as facilitators and provide students with conducive learning environment that promotes their understanding of science. Therefore, focus must be on the use of instructional approaches that make teachers facilitators, allowing learners to explore in a very efficient learning environment. Fortunately, a lot of studies have proposed computerized animations and models as one of such instructional approaches. For example, Akilli (2021) has reported that 3D computer models enhance students' mental models' construction and conceptual change. In his study with undergraduate science teachers in Turkey, he found that learners who were exposed to 3D computer models had more correct and clear mental models as compared to those exposed to 2D representations involving pictures and figures in textbooks. This also allowed learners exposed to 3D computer models explore better in the construction of knowledge. Tasker and Dalton's (2006) study on animations reported that, to use animations effectively, students' attention must be directed to key features, avoid overload of working memory, and encourage integration of prior knowledge meaningfully. They added that, this can be achieved by using constructivist learning strategies that inform us of what students already know and how they learn. Again, their findings reported that, to identify and prevent misconceptions during the use of animations, there should be a planned method to help students visualize the molecular level and evaluate their in-depth understanding of the structures and processes at that level. All these literatures discussed showed that the constructivist learning theory appropriately supported this present study.

2.7.2 Conceptual change theory

Numerous findings of students' understanding of scientific concepts have been reported in literature. Most of these reported students' prior conceptions are usually different from those accepted by science. These wrong perceptions are differently captioned as misconceptions, alternative conceptions, preconceptions, and pre-conceived ideas. Gilbert and Watts (1983) defined alternative conceptions as ideas that are not in line with those socially accepted by scientific community. Sources of students' alternative conceptions include personal experience, preconceptions, language barrier, lack of pre-requisite knowledge, overlapping of similar concepts, inability of students to visualize the sub-microscopic nature of matter (Garnett, Garnett & Hackling, 1995). Johnson (1991) stated that students' inability to link the three levels at which chemistry is represented (macroscopic, submicroscopic and symbolic levels) serves as a major cause of their misconceptions. He reported that, the abstract nature of chemistry, and students' inability to familiarize themselves with the submicroscopic level are key contributing factors to students misunderstanding. Findings reported by research on alternative conceptions and abstract nature of teaching and learning led to interest in considering conceptual change (Garnett, 2000). Conceptual change was introduced into education as an analogue from the history and philosophy of science due to the challenges people had switching from one explanatory framework to another (Agiande et al., 2015). One of the contemporary theories of learning that has aided in deepening our comprehension of constructivism is the conceptual change theory. Adesanya (2009) stated that, constructivists believe that as learners engage with their surroundings, they actively create new knowledge. Every experience one has is compared to what they already know, and if it makes sense in their mental world, they can acquire the new information. This knowledge is strengthened if they apply it successfully to a larger setting. According to Westbrook and Rogers (1992) in Agiande et al. (2015), conceptual change is the process of utilizing techniques to align the thinking of learners with that of scientists. This implies that, as students come to the classroom with various wrong ideas and perceptions, teaching strategies must be focused on assisting them change such wrong ideas and accept the scientifically accepted concepts. Agiande et al. (2015) concluded that, conceptual change describes what takes place when a learner enters a learning environment with past information that may be wrong and needs to be clarified or eliminated in order to accept a more accurate conception.

According to Hewson (1992), there are three context-specific meanings for change; it can be understood as extinction, extension or exchange. Conceptual change theory of learning views information acquisition as a process of knowledge extension and as an exchange of false beliefs for useful knowledge. This suggests that in order to acquire new idea, a student must comprehend it, accept and consider it beneficial. However, if a new concept or idea conflicts with one already held within the conceptual ecology of the learner, it cannot be accepted until the status of the conflicting conception is lowered. Therefore, relatively small change is done on his or her prior conceptions; this is called weak restructuring (Carey, 1985). On the contrary, a more radical change occurs when prior knowledge must be abandoned in order to accept new conception; which is known as conceptual exchange (Hewson, 1992) or radical restructuring (Carey, 1985). Vosniadou (1994) opined that, conceptual change has its origin in both cognitive science and studies on scientific education. He added that, research studies on conceptual change focus on how misconceptions arise and how to correct them through instruction. According to Anne, Ilka and Cornelia (2010), conceptual change processes can be described as learning routes from common conceptions or alternative ideas formed during instruction towards scientific concepts. Conceptual explanations are combined and incorporated into a larger network. There are various methods for theorizing these routes. The authors added that, Vosniadou's theory, which characterizes conceptual development as a change of firmly held presuppositions and ideas, is a well linked approach in science teaching. It is expected that students would create mental models to solve difficulties they face. These models are designed to be limited in their development by the individual's prior knowledge. When a piece of knowledge conflicts with one of a learner's presumptions or beliefs, it is recommended that, instead of modifying the presumption, a synthetic model must be created. This mental representation may satisfy the new knowledge as well as the corresponding prior premise or belief. Hence, synthetic models represent reliable knowledge for the individual. Based on several previous studies reviewed by Anne, Ilka and Cornelia (2010), they concluded that, though there are differing opinions on how to precisely represent learning processes, there is a general consensus that conceptual change does not correspond to a straightforward type of learning, involving mere addition of a few facts. Instead, it is seen as a learning process where conceptual frameworks must be substantially reorganized to enable comprehension of the intended content. In addition, Duit (2009) reported that, most modern researchers posit that many conceptions can co-exist rather than viewing conceptual change as an external or replacement of ideas as it was initially understood. Based on this viewpoint, learners typically do not discard their earlier conceptions but rather add new ones and relate them to their existing knowledge in a variety of ways. This perspective therefore explains conceptual change as the growth of metaconceptual knowledge. Anne, Ilka and Cornelia (2010) believe that, in order to achieve this, it calls for developing learners' metacognition awareness. Therefore, one of the most crucial elements in assisting with long-lasting conceptual change processes seems to be fostering students' metaconceptual awareness. It appears essential that students understand their own ideas and opinions as well as the similarities and contradictions between them and scientific ones (Mikkila-Erdmann, 2001; Vosniadou, 1994). Modelling in education must be characterized by the ability to select a model that is appropriate for the situation at hand and to be aware of the advantages and disadvantages of each model. In support of this, Nieswandt (2001) proposed that, it is essential for students to learn about a variety of situations in which the scientific concept can be used more successfully than everyday beliefs in order to encourage the development of flexible knowledge. A strategy to engage learners in conceptual change processes has been answered by many studies, by the use of cognitive conflict. It has been reported that the method of inciting a cognitive conflict through an experiment, text, or dialogue is an effective way to launch conceptual change processes because when learners are faced with anomalous situations, they don't just abandon their concepts (Mason, 2001). This approach has proved to be better than methods that provide a new idea without challenging students' existing ideas (Guzzetti et al.,1993). According to Anne, Ilka and Cornelia (2010), studies on students' thoughts have revealed that there are neither easy research recipes nor teaching recipes. However, careful selection of learning opportunities is necessary when setting up learning environments to promote conceptual change.

Computerized animations and models can be used as appropriate tools in this context. It has been proven that animations and models which highlight and debunk misconceptions support students better in acquiring scientific content than the conventional ones in books (Koomson, Safo-Adu & Antwi, 2020; Akilli, 2021). Understanding how to use models effectively is crucial for academic achievement in science classes as well as for social success. They serve as effective media for students to truncate between the different levels that chemistry is represented. In addition to this view, De Jong, Van Driel and Verloop (2005) opined that, making observations on the macroscopic level and utilizing models to explain these observations on the submicroscopic level alternate constantly in chemistry. They added that, whereas novices, like students struggle to understand the connection between model and phenomenon, professionals like teachers, can effortlessly and frequently shift between the various levels. Posner et al. (1982, p. 213) proposed four key prerequisites that must be met for conceptual change in science learning;

1. Dissatisfaction with current ideas must exist.
2. A novel, understandable conception is required.
3. The novel idea must appear to be sustainable in the long term.
4. The new idea ought to imply the likelihood of a successful program.

Hewson (1982) in Agiande et al. (2015, p.399) also recommended five ways teachers can effectively fulfil conceptual change in teaching;

1. Teachers need to be knowledgeable about the phenomena, techniques, ideas, and theories that make up what they teach.
2. Teachers should be aware of the students' preconceptions of the topics to be taught as well as the degree to which those preconceptions are supported by science.
3. Teachers need to understand that prior knowledge helps learners comprehend new information.
4. When students' pre-existing concepts contradict with those being taught, teachers must be persuaded of the necessity of using conceptual change teaching approaches.
5. Teachers must be able to organize and carry out teaching activities that put these ideas into practice.

These recommendations by Hewson (1982) as cited in Agiande et al. (2015) were taken into consideration in the present study. Students' prior knowledge and difficulties they faced in learning hybridization and molecular shapes were identified, and intervention that can effectively address the identified difficulties was developed. Moreover, when studying chemistry without some representations like animations and models, students are forced to think at a very high degree of abstraction. Therefore, in order to facilitate effective thinking processes, the current study presented computerized video animations and visualization models such as 3D models of atomic orbitals, video animations on formation of sp, sp^2 and sp^3 hybrid orbitals, videos displaying rotation of molecules depicting their bond angles and shapes. The principles identified in literatures on conceptual change best align with that of the present study, and hence support this study.

Furthermore, this study focused on improving students' performance in a topic they have been taught already. This implied the students already had prior knowledge that needed to be changed or modified. It was therefore relevant to select the constructivism learning theory which focuses on identifying students' prior knowledge before making any change or modification. Also, from literature reviewed, one major principle of the conceptual change theory is that, it allows students to switch between one framework to another framework. This study created a learning atmosphere that allowed the students to switch from wrong framework to another framework in order to appreciate the correct concept. This made it relevant to select the conceptual change theory to complement the constructivism theory.

Lastly, literature discussed earlier generally proposed a very strong coordination between the conceptual change theory and the constructivism theory, and therefore the researcher identified that both theories appropriately support the present study. The use of computerized animations and models in the construction of mental models, conceptual change or modification of prior knowledge are all in line with the principles of both constructivism and conceptual change theories that underpinned the present study.

2.7.3 Hybridization and molecular shapes

Hybridization is a term used to describe the mixing of atomic orbitals in an atom to generate a set of hybrid orbitals (Chang, 2010). Hybrid orbitals have different shapes from those of original atomic orbitals that mixed. It occurs between orbitals of the same atom; usually the central atom, and not between orbitals of different atoms. Hybrid orbitals are atomic orbitals obtained when two or more non-equivalent orbitals of the same atom combine in preparation for covalent bond formation (Chang, 2010) The mixing orbitals generally belong to the same energy level (say 2s and 2p orbitals may hybridize). The total number of hybrid orbitals formed after mixing, is equal to the number of atomic orbitals mixed. The name of the new hybrid orbital is obtained from the atomic orbitals involved. The present study considered three types of hybridization which are treated at the senior high school level; sp^3, sp^2 and sp.

2.7.3.1 Formation of sp hybrid orbital

It is formed from mixing of one s-orbital and one p-orbital of the same atom to give two sp-hybrid orbitals (Petrucci, 2007). The process is called sp hybridization. Each sp hybrid orbital has 50% s-character and 50% p-character. Orbitals generated are the seat of electrons which have a tendency to repel and be farther apart. Therefore, molecules formed by an sp-hybridized central atom have a linear shape and separated at a bond angle of 180°. Figure 2 shows a diagram of the formation of sp hybrid orbital.

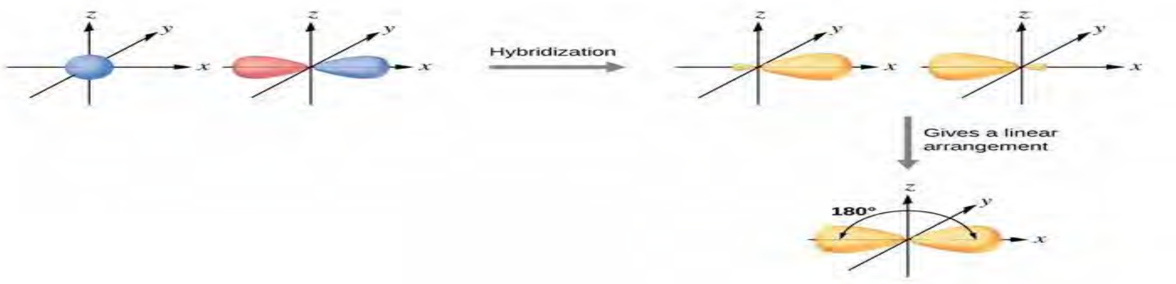

Figure 2: Formation of sp hybrid orbital (www.coursehero.com/study)

2.7.3.2 Formation of sp^2 hybrid orbital

It is formed from mixing of one s-orbital and two p-orbitals of the same atom to give three sp^2 hybrid orbitals. The process is called sp^2 hybridization. Each sp^2 hybrid orbital has 33% s-character and 67% p-character. Molecules formed by sp^2-hybridized central atom have a trigonal planer shape and separated at a bond angle of 120°. Figure 3 shows a diagram of the formation of sp^2 hybrid orbital.

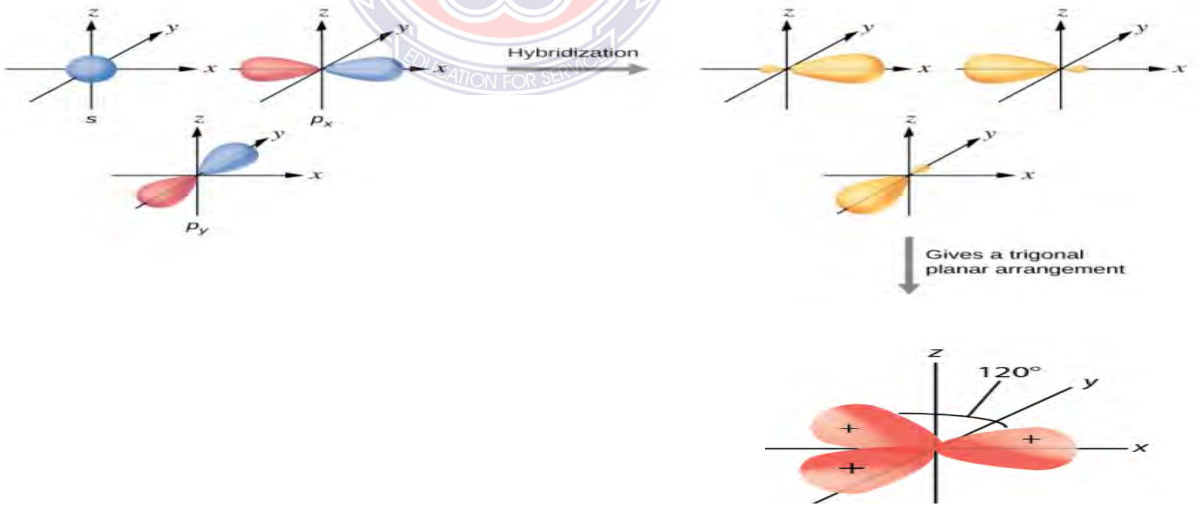

Figure 3: Formation of sp2 hybrid orbital (www.coursehero.com/study)

2.7.3.3 Formation of sp^3 hybrid orbital

It is formed from mixing of one s-orbital and three p-orbitals of the same atom to form four sp^3 hybrid orbital (Petrucci, 2007). Each sp^3 hybrid orbital has 25% s-character and 75% p-character. The orbitals are arranged tetrahedrally with a bond angle of 109.5°. Figure 4 shows a diagram of the formation of sp^3 hybrid orbital.

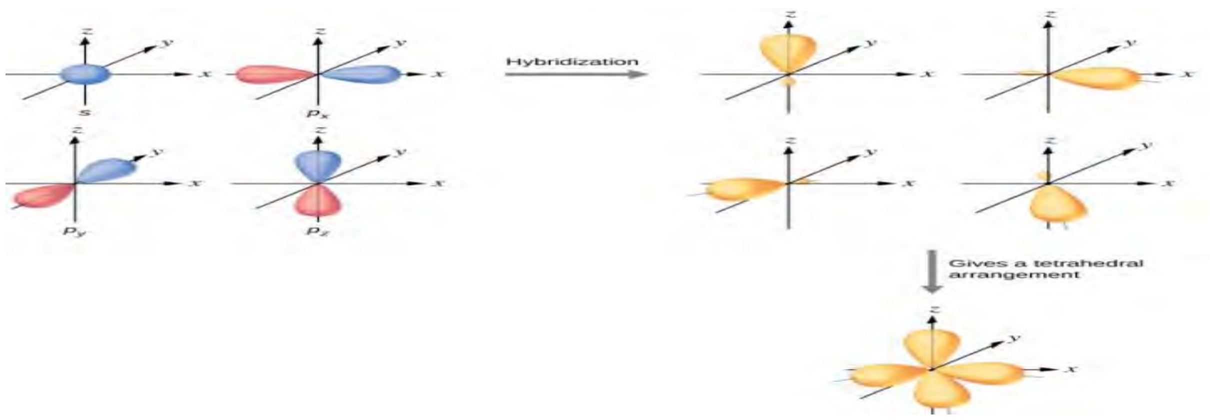

Figure 4: Formation of sp3 hybrid orbital (www.coursehero.com/study)

2.7.3.4 Molecular geometry or shapes

Molecular geometry is the three-dimensional arrangement of atoms in a molecule (Chang, 2010). It is determined by the central atom, atoms surrounding the central atom, and the electron-pairs around the central atom. This implies that, electron-pairs can give rise to another geometry called electron-pair geometry. The electron-pair geometry represents all regions where bonding electrons and non-bonding electrons (lone-pairs) are found around the central atom. The molecular shape or structure is the location of atoms around the central atom. In molecules without lone-pairs around the central atom, the electron-pair geometry will be the same as the molecular geometry. However, in the presence of lone-pair(s) around the central atom, the electron-pair geometry will be different from the molecular geometry. Molecular geometry of a molecule affects its physical and chemical properties such as boiling point, melting point, density, and types of reactions involved. Generally, experiments are used to determine molecular geometry (Petrucci, 2007). However, there have been procedures used to predict the correct molecular shapes of molecules or ion. One common procedure is the valence-shell electron-pair repulsion (VSEPR) model, which uses the geometric arrangement of electron-pairs around the central atom based on the Lewis dot and structure concept.

2.7.3.5 Effects of lone-pairs on molecular shapes and bond angles

Molecules whose central atom has both bonding pairs and lone-pairs make the geometry determination very difficult (Petrucci, 2007). This is due to the repulsive forces between bonding pairs, lone-pairs, and between bonding pair and lone-pair. According to the VSEPR model, the repulsive forces increase in the order; bonding pair - bonding pair repulsion < lone-pair - bonding pair repulsion < lone-pair - lone-pair repulsion (Chang, 2010). These repulsions result in changing the expected bond angles and shapes of the molecules involved. The following section presents some molecules and the effects of lone-pairs on their bond angles and shapes respectively.

2.7.3.6 Hybridization and bonding in CH_4, NH_3 and H_2O

The VSEPR theory proposed tetrahedral electron-group geometry for four electron groups around the central atoms in CH_4, NH_3 and H_2O molecules (Petrucci, 2007). However, due to the lone-pairs available in the NH_3 and H_2O molecules, they do not have a tetrahedral shape and expected bond angle of 109.5°. To explain bonding formation in CH_4, the valance bond theory used the concept of hybrid orbitals. Therefore, carbon forms four equivalent hybrid orbitals by mixing 2s, 2px, 2py and 2pz orbitals. Figure 5 shows the mixing of sp^3 hybrid orbital in carbon.

Figure 5: The mixing of sp^3 hybrid orbitals in carbon (www.coursehero.com/study)

Since the new hybrid orbital is formed from one s and three p-orbitals, called sp^3 hybrid orbital. The four hybrid orbitals are directed towards the four corners of a regular tetrahedron with bond angle 109.5°. In the formation methane (CH_4), the four sp^3 hybrid orbitals of C overlap axially with s-orbitals of the four hydrogen atoms to give four C-H sigma bonds, and hence gives CH_4 molecule both tetrahedral electron-pair geometry and shape as shown in Figure 6.

Figure 6: The tetrahedral shape and bonding in CH_4 (Petrucci, 2007)

Considering NH_3 molecule, the central atom, N is also sp^3 hybridized (2s^2, 2px^1, 2py^1, 2pz^1). However, the molecule does not have bond angle of 109.5° and so does not have tetrahedral shape. Explanation to this is that, one of the sp^3 hybrid orbitals of N is occupied by lone pair of electrons (Petrucci, 2007). Though NH_3 has tetrahedral electron pair arrangement, the lone pair electrons repel the bonding pair electrons which reduce the tetrahedral bond angle from 109.5° to 107°. Due to the lone-pair, only three of the sp^3 hybrid orbitals are involved in bonding with s-orbitals of three hydrogen atoms. The hybrid orbital will contain both the lone-pair and the bonding pair electrons, which makes NH_3 molecule attain a tetrahedral electron-pair geometry, but a trigonal pyramidal shape of bond angle 107° as shown in Figure 7.

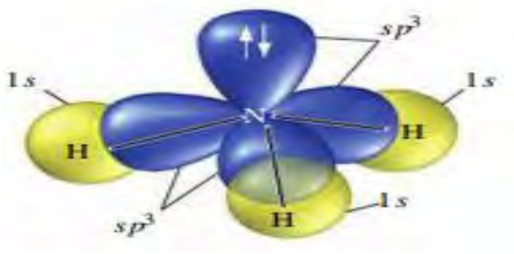

Figure 7: The trigonal pyramidal shape and bonding in NH_3 (Petrucci, 2007)

The central atom in H_2O also has tetrahedral electron geometry, however, two of the sp^3 hybrid orbitals are occupied by lone pair of electrons. The lone pair electrons repel the bonding pair electrons which reduce the tetrahedral bond angle from 109.5° to 104.5°. Therefore, H_2O has a tetrahedral electron-group geometry but has an angular or V-shape with bond angle 104.5°. Figure 8 shows the comparison effect of lone-pairs on the shape and bond angles of CH_4, NH_3 and H_2O.

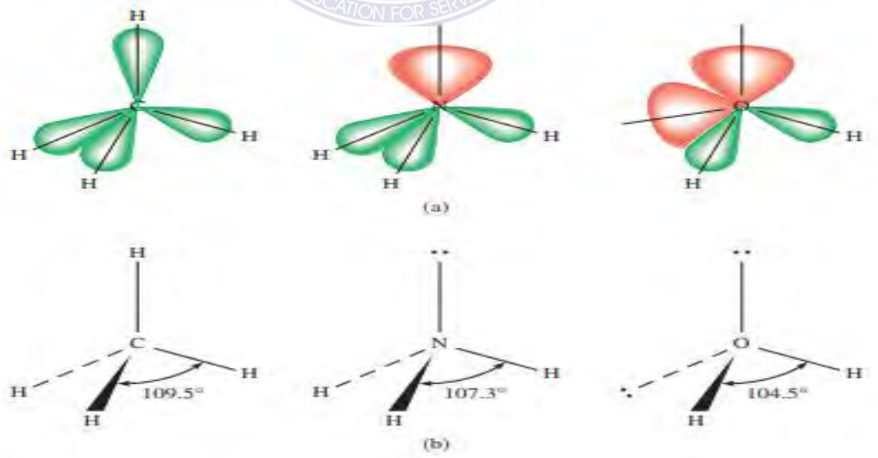

Figure 8: Relative sizes of bonding pairs, lone-pairs and bond angles in CH4, NH3 and H2O (Chang, 2010).

2.7.3.7 Formation of multiple bonds

An atom may achieve it octet by sharing more than one-pair of electrons with neighboring atom. Two shared-pair of electrons forms a double bond, three shared-pair of electrons forms a triple bond. The unique nature of carbon makes it possible to form single, double and triple bonds with other carbon atoms or another element. Let consider hybridization of the carbon atoms in ethene. The ground state and excited state configurations of C are $1s^2$, $2s^2$, $2px^1$, $2py^1$ and $1s^2$, $2s^1$, $2px^1$, $2py^1$, $2pz^1$ respectively. After excitation, the 2s, 2px and 2py orbitals mix to give three equivalent sp^2 hybrid orbitals. The unhybridized 2pz orbital lies perpendicular to the plane of the hybridized carbon atom with its two lobes disposed above and below the plane of hybrid orbitals as shown in Figure 9.

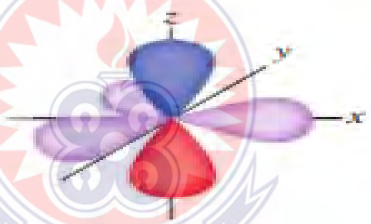

Figure 9: Three sp^2 hybrid orbital with unhybridized 2pz-orbital (Petrucci, 2007)

To form ethene, sp^2 hybrid orbital of one carbon overlaps axially with sp^2 hybrid orbital of the other carbon to give sp^2- sp^2 C-C sigma bond. The unhybridized 2pz orbitals of the two carbon atoms undergo a side-way overlap to form a pi (π) -bond. Therefore, the carbon-carbon double bond in ethene is made up of one σ bond and one π bond. The remaining two sp^2 hybrid orbitals of each carbon overlap axially with s-orbital of two hydrogen atoms. The shape of ethene is therefore trigonal planar, with a bond angle of 120° as shown in Figure 10.

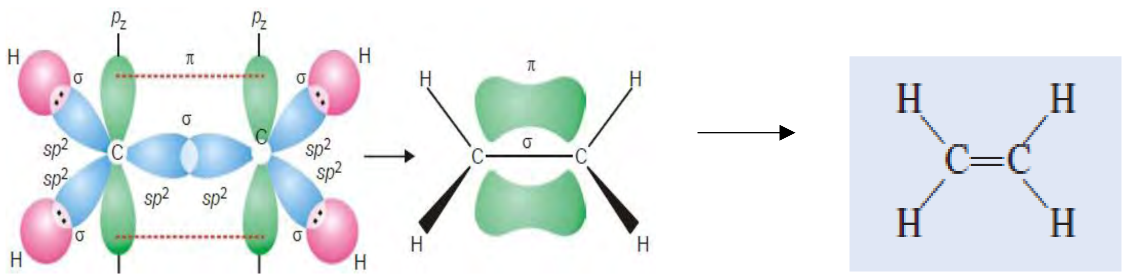

Figure 10: The formation of carbon-carbon double bond in ethene (Petrucci, 2007)

In carbon-carbon triple bond formation as in ethyne, the unhybridized 2py and 2pz orbitals of one carbon overlap with the 2py and 2pz orbitals of the other carbon to form two pi bonds. The remaining sp-hybrid orbital of each carbon then overlap with an s-orbital of one hydrogen atom to form ethyne as shown in Figure 11.

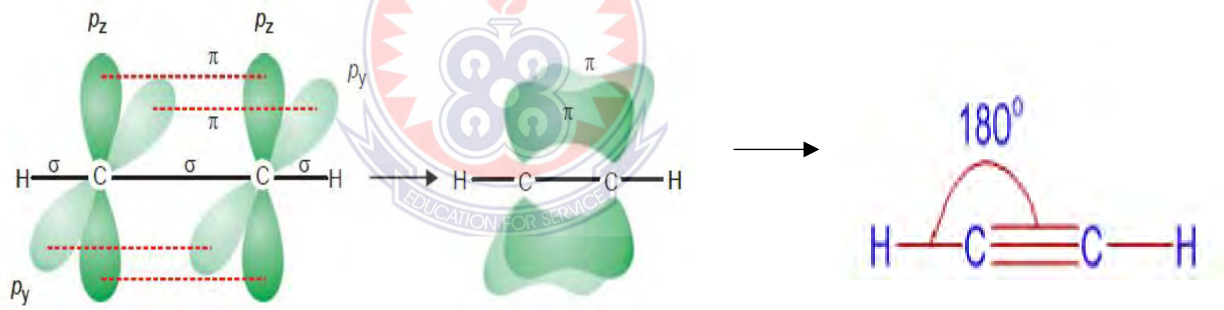

Figure 11: The formation of carbon-carbon triple bond in ethyne (Petrucci, 2007)

2.8 Conceptual Framework

Conceptual framework is a model that presents the various variables and the relationship among them (Mutai, 2000). The conceptual model underlying this study is concerned with improving students' performance in hybridization and molecular shapes using computerized animations and models. The independent variable is a computerized video animations and models instruction, whereas the dependent variable is students' performance (scores) on hybridization and molecular shapes test. The independent variable relationship showing how it affects the dependent variable forms the conceptual framework of the study. The relationship between the variables involved is shown in Figure 12.

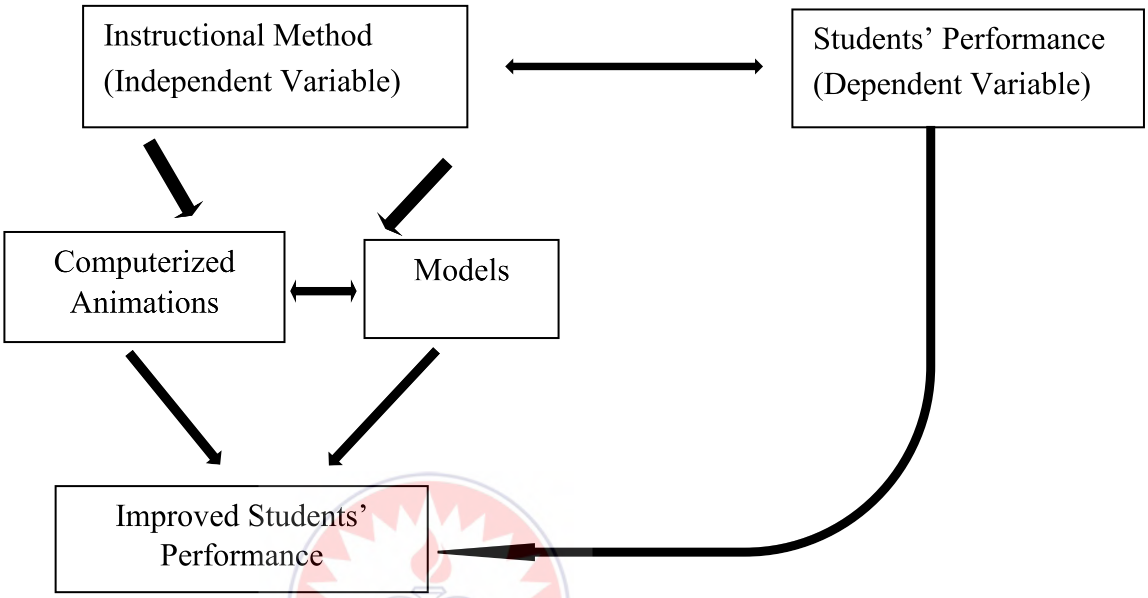

Figure 12: Conceptual framework of the study

2.9 Empirical Framework

This section highlights empirical studies on the effects of computerized animations on students' performance, as well as the differential effects of computerized instructional packages on male and female students' performance.

2.9.1 Effects of computerized animations on students' performance

One major breakthrough of animation which is still applied in mathematics today is its usage in teaching Pythagoras theorem. Thompson and Riding (1990) used an animation to teach Pythagorean theorem to junior high school students. Their study was an experimental study involving three groups. They developed graphic showing a triangle and three squares with each square sharing one of the triangle's sides. It showed that the area of the square along the hypotenuse was the same as the combined areas of the two other squares. The first group viewed a static graphic, the second group viewed discrete animation of the steps displayed on paper graphic, whereas the third group viewed a continuous animated video of the steps. The researchers found that, the third group that viewed the continuous animated video outperformed the other two groups that viewed graphics. In addition, Kieras (1992) investigated the effects of animated and static graphics on students' ability to understand the operation of an energy system. He found that, students who were exposed to continuous animations performed significantly than those exposed to static graphic. Park and Gittelman (1992) evaluated students' ability to learn the operation and troubleshooting of an electronic circuit. One group viewed the operation from a static graphic, whereas another group viewed the operation from an animated graphic. Findings reported that, the group exposed to animated graphic performed better than those exposed to static graphic.

Ozmen, Demircioglu and Gokhan (2009) conducted an experimental study to investigate the effects of animations on overcoming 11th grade students' alternative conceptions of chemical bonding. Results of their study revealed that, the group exposed to animations performed higher, and were better in remediating their alternative conceptions than those that were taught with the traditional approach.

Gambari, Falode and Adegbenro (2014) studied the effectiveness of computer animations and geometric instructional model on junior secondary school mathematics students' achievement and retention. It involved a pre-test-post-test experimental and control group design, comprising 30 male and 30 female students sampled using stratified sampling technique from two junior secondary schools in Nigeria. The study investigated three levels of independent variables; two experimental groups and one control group. The first experimental group (Group 1) was taught six topics on geometry for a period of four weeks using Computer Animation Package (CAP), the second experimental group (Group 2) was taught the same topics on geometry for four weeks using Geometric Instructional Model (GIM). The third group was control group (Group 3), this group was taught the same topics on geometry using Traditional Teaching Method (TTM) within the same period. The six topics on geometry taught were Cube, Cuboid, Cylinder, Cone, Spere and Hemisphere, and Pyramid. Geometry Achievement Test (GAT) was the data collection tool, and data were analyzed using Analysis of Variance (ANOVA) and t-test statistics. One-way ANOVA was used to determine if there was a significant difference between the post-test scores of the three groups. Results revealed that, there was a significant difference (Fcal = 64.022, df = 59, p = 0.00) between the three groups. Scheffe's post-hoc test was conducted on the data to determine the direction of the difference between the three groups. Scheffe's post-hoc analysis of the means scores for the Experimental Group 1, Experimental Group 2, and the Control Group were 73.20, 64.10 and 54.90 respectively. This indicated that there was a significant difference in the post-test mean scores of students in the three groups, which was in favour of the group exposed to computer animation package (Group 1). To determine the differences in retention between the three groups, post-test retention test scores for the three groups were subjected to Analysis of Variance (ANOVA). The results from the ANOVA reported post-test retention mean scores of 70.40, 60.20 and 51.65 for the groups exposed to CAP, GIM and TTM respectively. This clearly showed that, the computer animation package significantly improved students' retention in geometry compared to both geometric instructional model and the traditional teaching method. Based on these findings, they concluded that, computer animation is a very effective tool for teaching the concept of geometry in mathematics. The work is related to the present study since it studied the effectiveness of computer animations on teaching geometry in mathematics, whiles the present work studied the effectiveness of computer animations on teaching molecular geometry in chemistry. The study differs from the present study as it investigated the effect of animations on students' retention ability, which was not investigated in the present study. The study did not investigate the differential effect of animation on males and females; however, the present study investigated the differential effect of computerized animations and models on male and female students.

Dziedzic et al. (2015) investigated the roles of computer animations in teaching technical subjects. They proposed that computer animations have a positive effect on knowledge memorization by students, and are conductive to the development of the mind, animations help students to familiarize themselves with the schemes of solving technical problems, which make computer animations found wide usage in many science fields. In engineering field, computer animations are created using different types of applications which form a basic tool of a modern engineer.

The rapid development of multimedia technology prompted Ismail et al. (2017) to investigate the use of animated video teaching on the imagination and visualization of Malaysia College students in engineering drawing. The research design was a survey method with quantitative research approach. Questionnaire was used as the data collection tool, and analyzed using SPSS. Findings from the study reported that, video animation significantly increased students' understanding, motivation, imagination and visualization. It made learning more interesting, as the video animation had user friendly features that allowed students to directly operate in order to enhance imagination and visualization. Animations have quality learning materials that helped reduce students' cognitive load.

Ikwuka and Samuel (2017) in an experimental study investigated the effect of computer animations on 100 secondary school chemistry students in Nigeria with respect to academic achievement. These 100 students were selected from two randomly sampled secondary schools, in which one group was taught chemical reactions using traditional method, while the other group (experimental group) was treated chemical reactions using computer animations. Chemistry Achievement Test (CAT) was the research instrument, and Analysis of Covariance (ANCOVA) was the statistical tool used for data analysis. They found that; performance of students exposed to computer animations significantly improved compared to those taught with the traditional approach. The computer animations employed in the study to teach chemical reactions added real value to the teaching and learning of chemistry concepts, and improved the efficiency of information assimilation. In addition, the computer animation improved the teachers' teaching strategies for teaching difficult and abstract concepts. They further recommended the provision of necessary materials like computers and projectors for teachers to enhance their teaching process with animations. The study is linked to the present study, as both studies investigated the effect of computer animations on students' performance, and differential effects on male and female students. However, quasi-experimental design was used in the study, whiles case study with action research approach was used in the present study. In addition, the study employed computerized animations whereas the present study employed both computerized animations and models.

Chikendu (2018) conducted a quasi-experimental study to examine the effect of instructional computer animation on secondary school students' achievement and interest in chemistry. The poor performance of chemistry students in secondary school certificate examinations prompted this study. The study focused on determining the effect of the use of instructional computer animation on students' achievement and interest in chemistry. The sample population was 186 students, from two secondary schools drawn out of 46 secondary schools in Awka Educational Zone, Anambra State. The study employed a quasi-experimental design, with control and experimental groups comprising of 95 and 91 students respectively. Instruments that were used to collect data for the study were Chemistry Achievement Test (CAT) and Chemistry Interest Scale (CIS). Data were analyzed using mean and standard deviation, null hypotheses were tested at 0.05 significance level using Analysis of Covariance (ANCOVA). Findings of the study revealed that, the post-test mean scores of the group exposed to computer animations was 76.86, whereas that of the group exposed to regular conventional method was 54.43. This showed that the use of computer animation helped the experimental group achieved higher than their counterparts in the control group. This also indicated that, computer animation as instructional approach had significant effect on students' achievement in chemistry. In addition, computer animations increased the low performing students' interest, engagement and achievement compared to those exposed to conventional method. This study is related to the present study since both investigated the effect of computerized animation on students' performance in chemistry. Both also investigated the influence of sex differences in reception to computerized animations. The differences between the two studies are; the present study investigated the effect of computerized animation in combination with 3D models. In addition, the present study employed a case study with action research approach.

Liu and Elms (2019) conducted a survey to explore the use of animated cartoon videos to teach advance undergraduate accounting students. The study comprised two cohort groups of 254 students in two different year groups (2017 and 2018). In their analysis, they identified specific areas that the animated videos enhanced during the students learning experience. They found that, the animated instructional videos raised students' engagement, interest, understanding and allowed a higher flexibility of self-directed learning.

Nuni et al. (2019) conducted a comparative study to determine the effectiveness of animated video on secondary school students' conceptual understanding of electronics. The animated video was downloaded from YouTube, and was identified as a very good resource for teaching the topic understudy. One hundred and sixty grade 12 students sampled from four secondary schools were used in the study. Research design employed in the study was Solomon Four quasi-experimental non-equivalent group pretest post-test randomized control group. Four intact classes were used in the study, with one intact class from each of the four schools. Two intact classes served as experimental groups and were taught electronics with animated video, whereas the other two classes served as control groups which were taught using traditional teaching method. Electronic Achievement Test (EAT) was the research tool used in the study. The difference in mean scores for pre-test was tested with t-test statistic, whereas the ANOVA was used to determine the difference between the experimental and control groups post-test mean scores. Findings revealed that, the post-test mean scores of experimental group 1 and experimental group 2 were 18.96 and 20.68 respectively, that of control group 1 and control group 2 were 15.43 and 9.90 respectively. This result indicated that, the performance of students taught with animated videos improved more than those taught with the traditional method.

ANOVA was used to determine if there was a statistical difference in the mean scores of the four groups. Results from the ANOVA revealed that, there was a statistical difference between the four mean scores. Based on this, it was concluded that, animated video was very effective for teaching electronics. This study is similar to the current study since both studies employed the use of video animations downloaded from YouTube. The difference between the two studies is that, the video animation was used to teach electronics in physics, whereas the present study used the video animation to teach hybridization and molecular shapes in chemistry.

Ejike and Opara (2021) also examined the effect of animation instructional strategy on senior secondary students' academic achievement and retention of chemical bonding. The animated instruction employed was animated videos on chemical bonding. The study population comprised of 6,234 first year secondary school students in Otuocha Educational Zone of Anambra State, Nigeria. The study adopted a pretest post-test control group quasi-experimental design. The study purposively selected two public senior secondary schools, based on availability of equipped computer laboratory and source of power for the presentation of the animation. One intact class was selected from each of the two schools, to serve as experimental and control groups. The sample population was 203 students, with 97 students in the experimental group and 106 students in the control group. The experimental group was taught chemical bonding using animated videos whereas the control group were taught the same concept using lecture method. Research instrument used for data collection was Chemical Bonding Achievement Test (CBAT) developed by the researcher. The CBAT was validated by three experts, and reliability index of 0.82 was obtained using Kuder Richardson (K-R-20). The data of the study were analyzed using statistical package for social and sciences (SPSS) version 20. The two research questions that guided the study were answered using mean and standard deviation. Two null hypotheses were tested at 0.05 level of significance using Analysis of Covariance (ANCOVA) statistic. The study findings reported that, the post-test mean achievement score of the group exposed to animated videos was 36.56, whereas that of the group exposed lecture method was 20.01. This result indicates that, students that were taught chemical bonding with animated videos performed better than those taught using lecture method. Analysis of Covariance (ANCOVA) of the post-test mean achievement scores between the two groups showed a statistically significant difference between the achievement scores of the experimental group and the control group in favour of the experimental group. With regard to retention of chemical bonding concepts, the retention test means achievement scores of the group treated with animated videos and the group treated with lecture method were 24.33 and 17.23 respectively. This represents an achievement mean difference of 7.1 in favour of those exposed to the animated instruction. In addition, Analysis of Variance (ANOVA) results of the retention test showed a significant difference in favour of the experimental group. This indicated that, the experimental group that was taught chemical bonding using animated videos retained the concept better than their counterpart in the control group. The study and the present study are related since both studies employed animated videos as instructional approach. Both studies also investigated the effect of animations on students' performance. The differences between the two studies are; the study investigated the effect of animated videos on students' achievement in chemical bonding, whereas the present study investigated the effect of video animations and models on students' performance in hybridization and molecular shapes. Also, the study investigated the effect of video animations on students' retention, but the present study investigated the differential effect of video animations on male and female students' performance.

Furthermore, Yanarates (2022) conducted a semi-experimental study to investigate the effect of teaching with animation on chemistry students' achievements and persistence in learning. The study consisted of 82 pre-service undergraduate teachers. The 82 participants were randomly divided into two groups; experimental and control groups. Both groups were taught chemistry lessons for six weeks, in which the experimental group was taught using animation techniques, whereas the control group was taught using traditional method. Data of the study was collected with Chemistry Achievement Test (CAT) developed by Sonmez (2017), Man-Whitney U-test, and analyzed with inferential statistics. Post-test scores of the experimental group and the control group showed a significant difference in favour of the experimental group. This indicates that, the use of the animation technique increased the students' knowledge level compared to the use of traditional method. After additional six weeks, retention test was also administered to the experimental group, and compared to their post-test scores to determine the effect of the animation on learning persistence. Spearman's Rank Correlation analysis results showed that, the post-test scores and the retention test scores significantly correlated positively ($r = 0.751$). This indicated that animations enhanced learning persistence or permanent learning. This study relates to the present study as both explored the effect of animations on students' performance, and its differential effect on males and females. However, it investigated the effect of animations on learning persistence, which was not explored in the present study.

Teplá, Teplý, and Šmejkal (2022) conducted a study to compare the effect of animations and 3D models to static visualization on students in biology, chemistry and geology. The study focused on looking at the effects on students' intrinsic motivation and learning outcomes. The study comprised of 565 students between the ages of 11 – 15 years in Czech. The animations and 3D model were used to treat the experimental group whiles the static visualization was used to treat the control group. Two research tools were used in the study; Motivation inventory and knowledge, Motivated strategies for learning questionnaire. Their findings reported that, 3D models and animations significantly increased students' intrinsic motivation for learning. In addition, 3D models and animations were found to significantly improve students' engagement, interest, competence and understanding of subject matter relevance. In terms of learning outcomes, it was reported that, students exposed to 3D models and animations achieved significant higher level of chemistry knowledge compared to the group exposed to traditional approaches. Among the three natural subjects (biology, chemistry and geology) used in the study, the greatest positive effect of animations and 3D models were identified in chemistry and biology. The similarity between this study and the present study is that, both employed the use of animations and 3D models, however, the earlier study investigated their influence on learning outcomes in biology, chemistry and geology. The study also investigated the influence of computer animations and 3D models on students' intrinsic motivation and interest, but did not consider the differential performance between males and females exposed to computerized animations and 3D models. The present study investigated the differential effect of video animations and models on male and female students' performance. Moreover, the study employed a quasi-experimental design, whereas the present study employed a case study design with action research approach.

2.9.2 Differential effects of computerized instructional packages on male and female students' academic performance

Gambari, Falode and Adegbenro (2014) investigated the effectiveness of computer animation and geometry instructional model on junior secondary school mathematics students' achievement in Minna, Nigeria. The study also examined the differential mean performance and retention of male and female students exposed to computerized animation package, geometric instructional model, and traditional teaching method. The study employed a pre-test experimental and control group design, with a sample size of 60 students; 30 males and 30 females. Geometry Achievement Test (GAT) was research tool used for data collection. The first experimental group was treated geometry using computerized animations, the second experimental group was taught using geometric instructional model, whereas the control group was taught using traditional method. To determine the differential mean performance between the males and the females, the post-test scores of the group taught geometry with computerized animations were analyzed using t-test statistic. Results from the statistics revealed that, the mean achievement scores for male and female students were 73.20 and 71.80 respectively. This shows that, the achievement scores of the male students were slightly higher than that of the females, but did not differ significantly from that of the females after they were taught geometry using computer animations. Based on this, it was concluded that, there was no significant difference between the mean achievement scores of male and female students exposed to computerized animations. In addition, the post-test performance scores between male and female students exposed to geometric instructional model and the traditional teaching method were also analyzed using t-test statistics. Results revealed that, the mean achievement scores for male and female students were 64.60 and 62.60

respectively. This also shows that the achievement scores of male students were slightly higher than that of the females, but did not differ significantly. This was also concluded that, there was no significant difference between the mean achievement scores of male and female students exposed to geometric instructional model and traditional teaching method. Based on this analysis, it was concluded that, there was no significant difference in performance between males and female in reception to computerized animation.

Owolabi and Ogini (2014) investigated the effectiveness of animated-media approach on achievement, retention and interest among geography students at the secondary school level in weather concepts. The study also focused on finding out the differential effect of the animated-media on male and female students' achievement. The study population comprised 699 second year students of Kurfi Educational Zone of Katsina State, Nigeria. The study employed a quasi-experimental design with pretest-post-test design. The sample population comprised 116 students. Research tools used for gathering data were Weather Concepts Achievements Test (WCAT) and Weather Concepts Interest Questionnaire developed by the researcher. The experimental group was taught weather concepts using animated-media strategy whereas the control group was taught using conventional lecture method. Four research questions guided the study, and four null hypotheses tested at 0.05 level of significance using t-test and Mann-Whitney U-test. Data were analyzed using descriptive statistics of mean and standard deviation. Findings from the study revealed a significant difference in academic achievement, retention and interest between the group exposed to animated-media and those exposed to conventional lecture approach. The group exposed to the animated-media significantly performed better, retained the weather concepts better, and showed a higher positive interest than their counterparts in the control group. However, the study revealed no significant difference in academic achievement, retention and interest between male and female students exposed to the animated-media. Results of this study implies that, animated-media instructional package have similar effect on both male and female students.

Olanrewaju, Better and Ngozi (2016) examined the effect of computer assisted instruction on senior high school students' achievement in chemical reaction and equilibrium. Purposive sampling technique was used to select three public secondary schools in Oyo State, Nigeria. The study employed a quasi-experimental study of pre-test post-test non-randomized control group design. Simple random technique was employed to select intact classes into control and experimental groups. The sample population comprised 55 students with 24 males and 31 females. The experimental group which comprised 25 students were taught chemical reaction and equilibrium using computer assisted instruction, whereas two control groups; comprising 30 students were taught the same concepts using traditional methods. Chemical Reaction and Equilibrium Achievement Test (CREAT) was the research tool used for the study, and analyzed using mean, standard deviation and Analysis of Covariance (ANCOVA) at significant level of 0.05. Findings from the study revealed that, students exposed to the computerized instruction performed better than those exposed to the traditional methods. Analysis of experimental group post-test scores showed no significant difference in achievement between the male and female students. The study concluded that, the computerized instructional package has similar effect on both male and female students.

Ikwuka and Samuel (2017) conducted an experimental study that focused on determining the effect of computer animations on students' achievement, and the differential effect of computerized animations on the males and females. The sample population comprised 50 male and 50 female students from two intact classes selected from two secondary schools in Nigeria. One intact class served as an experimental group and was taught chemical kinetics, chemical equilibrium, and collision theory using computer animations. The control group was taught the same concepts using traditional method. Analysis of the post-test scores of the experimental group showed that, the post-test means scores of the male students and the female students were 65.78 and 45.66 respectively. A mean difference of 11.12 between the males and the females indicated a significant difference in academic performance in favour of the males when they were taught chemistry concepts using computer animations. This was concluded that, teaching chemistry with computer animation was more effective among male students than female students.

Julius, Twoli and Maundu (2018) investigated the effect of computer aided instruction on students' achievement in chemistry compared to the use of conventional instructional method. Four secondary schools were purposely sampled from fifteen secondary schools in Tharaka Nithi County, Kenya. The four schools were randomly assigned either experimental or control group; which produced four intact classes with two experimental groups and two control groups. The sample population from the four schools was 174 students, comprising of 83 males and 91 females. Chemistry Achievement Test (CAT) was the tool used for collecting data for the study. Data were analyzed using both descriptive and inferential statistics. The groups mean differences were analyzed using t-test, Analysis of Variance (ANOVA), and Analysis of Covariance (ANCOVA). A pre-test administered to determine the difference in performance between the male and female students showed no significant difference. This indicated that, the performance of male and female students was similar before the treatment. The experimental groups were taught atomic structure, periodic table and chemical families for six weeks whereas the control groups were taught the same concepts using conventional method for six weeks. The experimental group 1 comprised of 45 males, and experimental group 2 comprised of 46 females. The male students recorded a mean score of 25.60 with standard deviation of 3.360, whereas the female students recorded a mean deviation of 26.59 with standard deviation of 4.145. In addition, t-test analysis revealed a significant difference in performance between the male and the female students, in favor of the female students. The study results showed that, female students scored higher in chemistry than males after they were taught with computer aided instruction. It was concluded that, female students perform better than male students when exposed to computer aided instruction, and must be adopted by teachers to improve performance of females in chemistry.

Adekunle et al. (2021) conducted a study to investigate if the use of computer simulation as intervention can enhance the performance of female students compared to male students in senior secondary school chemistry. Therefore, the study focused on determining if computer simulation package can bridge the gap in performance between male and female students. The study was conducted in Ado-Odo-Ota, Nigeria. The study participants comprised 51 female and 32 male students, with average age of 14 years. The research design employed was quasi-experimental involving pre-test post-test non-equivalent group. The experimental group was taught with computer simulation while the control group was taught with a conventional lecture method. Data were collected with Achievement Test and analyzed using ANCOVA. Results of the study showed that, there was a statistical difference between the experimental group and the control group in favour of the experimental group. This means the computer simulation package had positive effect on students' performance. With regards to differences in performance between males and females, the mean scores of male and female students were 12.84 and 12.72 respectively. The study therefore reported no statistical difference between the performance of males and females when exposed to computer simulation package. Since the computer simulation improved the performance of both male and female students, similarly, it was concluded that the use of computer simulation package can bridge the gap between male and female students' performance in chemistry.

Ekundayo (2022) investigated the effects of computerized instruction on students' achievement in chemistry among males and females in public secondary schools in Ondo State, Nigeria. The computerized instructional software used was titled "Computer Interactive Device (CID)". Three schools were selected for the study, with one intact class from each school. The study adopted a quasi-experimental design with a total participant of 240 students. The experimental group was treated with the computer interactive device package whereas the control groups were taught using conventional teaching method. Chemistry Achievement Test (CAT) was used for data collection and analyzed using ANCOVA and t-test statistics at significance level of 0.05. To ascertain the differential mean performance between male and female students exposed to the computer instruction package, the post-test scores of the experimental group was analyzed using independent-samples t-test. Results showed that, the means achievement scores of male and female students were 22.63 and 24.51 respectively. This indicated a significant difference in achievement between male and female students exposed to the computerized instructional package, which was in favour of the female students. Results from the study concluded that, female students performed better than their male counterparts when they were exposed to computerized instructional package.

Experimental study was conducted by Yanarates (2022) to investigate the effect of animated teaching on chemistry students' achievements and persistence in learning. The study consisted of 82 pre-service undergraduate teachers, randomly divided into experimental and control groups. The experimental group was treated with animation for six weeks, whereas the control group was taught with traditional method for the same period. Chemistry achievement and persistent tests were the research tools used for collecting data for the study. Findings from the study showed that, the post-test means scores of male and female students were 36.15 and 49.25 respectively. This represented a significant difference between the male and the female students' achievement, in favour of the female students. This indicated that, the animated instruction significantly improved the performance of female students than their male counterparts.

2.10 Summary of Literature Review

The chapter discussed literature relevant to the study. It looked at review on the following sections; computerized instructional packages and performance, barriers in integrating computerized instructional packages in education, the use of models as teaching aids in science. In addition, it reviewed studies on spatial ability and learning with 3D computerized models, computerized animations as teaching aids in school chemistry, sex and performance in school chemistry. It also presented theoretical framework, conceptual framework, and empirical framework of the study.

Computer animation is a computer-generated series of images, frames, or graphics that depict the position of a specific item at various time intervals (Patete & Marquez, 2022). There are two modes of illustrating animations; static and animated. Animations are used for two main purposes; explanation of basic concepts, and provision of real-world context and application of existing knowledge. Empirical studies on animations have reported that computerized animations and models significantly improve students' performance, however, they can either reinforce misconceptions or create new misconceptions in learning science if not planned well. For animations to be effective, they must be learner friendly, devoid of distractors, and must be a representation of the phenomena under study. Models are used in science as representations of objects which are too small, unavailable or dangerous to handle. The type of model used for teaching affects the mental picture students create in their minds, hence appropriate models must be employed by teachers to prevent development of misconceptions among students. Spatial ability is the ability to create, maintain and effectively manipulate visual images. It is grouped into three aspects; spatial orientation, spatial relation, and spatial visualization. Barriers to integrating computerized instructional packages are classified into two; teacher related barriers and school related barriers. There is no consensus on which of the two poses the greatest barrier to ICT integration in education, however, the major barrier between the two is context-based.

Review of the relevant studies have shown that hybridization and molecular shapes are difficult topics for students at all levels. Some reasons reported as the causes of the difficulties were the abstract nature of the topics, teaching methods employed by teachers, students' alternative conceptions, and differences in students' sex. Based on these findings, several studies have called for the use of a more engaging instructional approach in teaching hybridization and molecular shapes. This study is in respond to this suggestion, as it tested the effectiveness of computerized video animations and 3D models as instructional approach for improving students' performance in hybridization and molecular shapes. From the literature reviewed, the use of computerized animations and models have been used in many studies, which have proven to be very effective for teaching abstract concepts in biology, physics, geology, technical, engineering, mathematics and chemistry. Therefore, this study focused on using computerized animations and models as instructional package to test the abstract nature of hybridization and molecular shapes as reported by previous studies. This study would therefore provide a lot of information that would help bridge the gap between reading and visualization of hybridization and molecular shapes.

Moreover, most of the studies on animations and models were done overseas, and therefore little is known about the impact of computerized animations and models (CAM) instructional package in teaching and learning in the context of Ghana. In addition, very few empirical studies are available in Ghana regarding the use of computer animations and models in chemistry. Hence, much remain to be empirically studied on the effect of CAM in chemistry education, in Ghana. This creates a gap which calls for an empirical study, hence this study.

Lastly, literature reviewed showed inconclusive findings reported by different researchers regarding the differential performance of males and females in reception to computerized instructional approach. Despite the valuable findings reported on sex differences in chemistry by previous studies, findings and recommendations given were context-based, which may not be applicable in other contexts. This also calls for the need to investigate if there is any difference in performance between male and female students exposed to computerized animations and models, in the Ghanaian context.

CHAPTER THREE

METHODOLOGY

3.0 Overview

This chapter deals with the description of methods and procedures that were used in carrying out this research study. The description is organized into the following sections; research design, study area, population, sample and sampling technique, instrumentation, validity of the main research instrument, reliability of the main research instrument, data collection procedure, pre-intervention activities, implementation of the intervention, post intervention activities, data analysis and ethical considerations.

3.1 Research Design

Research design is a strategy, plan, and framework for conducting research to find solutions to issues (Kumar, 2005). Case study design with action research approach was used in this study. A case study is an in-depth study of specific group, event, organization or phenomenon which is a very effective design for describing, evaluating, comparing and understanding different aspects of a research problem (McCombes, 2019). Action research approach was chosen because the present study aimed at investigating an issue and addressing it simultaneously. In addition, it is a participatory approach for gathering information that can be utilized to investigate teaching, curriculum development and learner behavior in the classroom (McCallister & Levitas, 2020). Purposes of action research approach are to address problems in a situation or to improve certain collection of conditions, and attempt to make changes (Burns, 2000). Therefore, the case study design with the action research approach helped the researcher to know more about the group, design an intervention to correct difficulties identified, as well as the effect of computerized animations and models on the students' performance. It therefore serves as both diagnostic and corrective. Based on these characteristics, case study design with action research approach was appropriate for this study. Figure 13 presents flow chart of the design of the study.

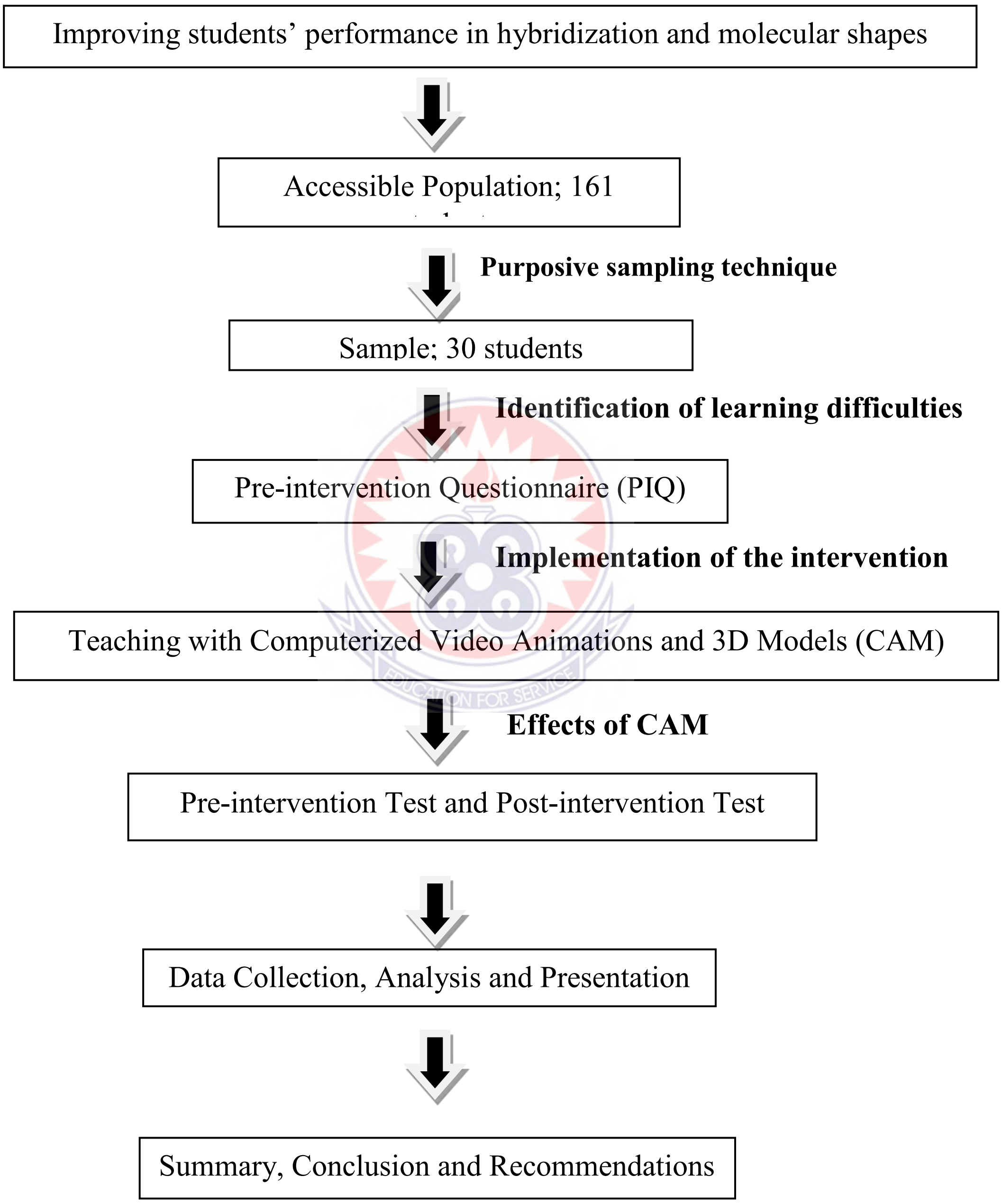

Figure 13: A flow chart of the design of the study

3.2 Study Area

The study was conducted at Anlo Senior High School, Anloga, which was established in 1959 in the Volta Region of Ghana. Anloga is a coastal town located in the Southern part of Volta Region, near Keta. The school is located along the Accra – Aflao road, and it is about one hundred and seventy-five kilometers from Accra. The main occupations of the people are farming and fishing.

3.3 Population

Target population for a study refers to all members or objects involved in a study (Kothari, 2004). The target population for this study was the chemistry students of Anlo Senior High School in the Volta Region. Anlo Senior High School is a mixed school with a total population of 1850 students at the time of the study. Programmes offered by the school include Agricultural Science, Business, General Art, General Science, Home Economics and Visual Art. The accessible population was the second-year chemistry students. This group was chosen for the study because they were the group the researcher identified the problem and intended to study and improve their performance. At the time of the study, the total second year chemistry students were 161, comprising 58 females and 103 males. There were five chemistry classes with an average class size of 31.

3.4 Sample and Sampling Technique

Purposive sampling technique was used to select one intact class for the study. According to Creswell (2008), purposive sampling helps the researcher to select the type of respondents with qualities which are appropriate for the study. Out of the five chemistry classes, the General Science 2B class was purposely selected for the study. The class consisted of 30 students, with 15 males and 15 females. That class was chosen as the researcher had knowledge of their poor performance in hybridization and molecular shapes. In selecting the intact class, the researcher did detailed inspection of exercise books of the five classes. The researcher found that, the performance of the Science 2B class on hybridization and molecular shapes was very poor compared to the other four classes. Moreover, for the sake of convenience, one of the classes taught by the researcher was used for the study. This made it easy and convenient for the researcher to gather enough data for the study.

3.5 Instrumentation

The study employed quantitative data gathering instruments. Two instruments were used for data collection; tests and questionnaires. The instruments were developed by the researcher. Instruments that were used to collect data for this study were Hybridization Performance Test (HPT) - through pre-intervention test (HPT-1) and the post-intervention test (HPT-2) results. Two set of questionnaires were also used; Pre-Intervention Questionnaire (PIQ-1) and Post Intervention Questionnaire (PIQ-2).

3.5.1 Hybridization Performance Test (HPT)

Hybridization Performance Tests (HPT) constructed by the researcher were used to evaluate the student performance before and after the intervention. There were two sets of hybridization performance tests; HPT-1 and HPT-2 which served as pre-intervention test and post-intervention test respectively. HPT-1 and HPT-2 are found in Appendix A and Appendix B respectively. The pre-intervention test (HPT-1) was administered to the respondents in the first week of the study in order to assess students' pre-intervention performance in hybridization and molecular shapes. Item analysis of the pre-intervention test helped the researcher to design an intervention that could respond to the students' difficulties. The pre-intervention test items were constructed from the following sub-topics; hybridization of atomic orbitals, formation of hybrid orbitals, sigma and pi-bonds, molecular shapes, and bond angles. The test items were constructed based on the six levels of cognitive domains; knowledge, comprehension, application, analysis, synthesis and evaluation. The test comprised fifteen (15) multiple choice questions, five (5) true or false, and two (2) short-answer items, totaling 30 marks. Four weeks was used for implementation of the intervention strategy.

After four weeks of teaching and learning with the computerized animations and models instructional approach, a post-intervention test (HPT-2) was administered to the students. This test was administered as a summative assessment of the students' performance in hybridization and molecular shapes after the intervention period. The post intervention test was also constructed based on the six levels of cognitive domains. It also consisted of fifteen (15) multiple choice questions, five (5) true or false, and two (2) short-answer items, totaling 30 marks. Administration of each test lasted for fifty minutes. Students' performance was based on scores obtained after marking the performance tests. Therefore, the pre intervention test scores and post intervention test scores were used to ascertain the effect of the intervention on the students' performance.

3.5.2 Questionnaires

Two sets of questionnaires were used in this study; Pre-intervention Questionnaire (PIQ-1) and Post Intervention Questionnaire (PIQ-2) as shown at Appendices C and D respectively. The Pre-intervention Questionnaire (PIQ-1) was used to solicit information on the challenges students faced on learning of hybridization and molecular shapes. It comprised sections A and B, with eighteen close-ended items. The Post Intervention Questionnaire (PIQ-2) was purposely structured to capture and solicit information on students' views about the integration of computerized animations and models as instructional approach for teaching and learning hybridization and molecular shapes. Therefore, the items focused on identifying the students' teaching and learning experiences in relation to their performance. PIQ-2 comprised eighteen closed- ended items that required students to indicate the extent to which they agreed or disagreed with statements in five-point Likert scale; Strongly Agree (SA), Agree (A), Uncertain (U), Disagree (D), and Strongly Disagree (SD).

3.6 Validity of the Research Instruments

Validity is the extent to which an instrument measures what it is designed or intended to measure (Thatcher, 2010). Content validity was ensured in designing the instrument. According to Creswell (2005), content validity is the degree to which test items and results cover every situation that can be asked on certain body of knowledge. To ensure content validity of the Hybridization Performance Tests (HPT-1 and HPT-2), they were given to experienced chemistry teachers and my supervisor for review. Based on their feedback, necessary modifications were done. This method was supported by Haradhan (2017), who opined that, there is no statistical tool to measure content validity, but it is based on the judgement of experts in the field. The tests were pilot tested to check data collection ability, clarity of responses, and whether they captured the required data. The pilot study sample comprised thirty form two chemistry students of Keta Senior High School. The pilot study helped to determine the reliability coefficients of the tests and the questionnaires.

3.7 Reliability of the Research Instruments

Reliability in quantitative research is the consistency, stability and reproducibility of results (Twycross & Shields, 2004). According to Kothari (2004), an instrument is reliable if it gives consistent results. To ensure reliability of the Hybridization Performance Tests (HPT), test-retest reliability method was employed. According to Haradhan (2017), test-retest reliability is a measure of reliability that is determined by administering the same test to the same group of people twice over a period of time ranging from few days to weeks. The test-retest reliability is computed by correlating the two sets of scores produced by the different measures. Pearson's product moment correlation coefficient was used to compute the reliability coefficient of the tests. Coefficient of reliability ranges between -1 and +1, where a negative reliability coefficient indicates negative association between variables; as one increases, the other decreases. A positive value indicates a positive association between variables; as one increases, the other also increases. A zero value indicates no association between the two variables.

Test-retest reliability method was employed to determine the reliability of each test. Therefore, the Hybridization Performance Tests (HPTs) were administered to thirty form two chemistry students of Keta Senior High School. After three days, the same tests were administered to the same students. After marking, scores of the pilot test were used to determine the reliability of the tests. The scores from both tests were computed using Microsoft Excel version 2019. The reliability coefficient (r) of the pre-intervention test (HPT-1) and post-intervention test (HPT-2) were found to be 0.81 and 0.79 respectively. According to Madan and Kensinger (2017), reliability coefficients above 0.70 are acceptable, and coefficient yield above 0.80 are very good. Therefore, reliability coefficients of 0.81 and 0.79 for the tests indicated that they were reliable to be used for the study. To test the internal consistency of the Likert scale questionnaire items, the researcher administered the questionnaire to the pilot group. Results from the students' responses were subjected to the reliability command in SPSS to determine the Cronbach's alpha value. The Cronbach alpha reliability coefficient was 0.808, which was very reliable for the study.

3.8 Data Collection Procedure

Before the intervention, the participants were briefed on the study. Hybridization Performance Test (HPT-1) was administered to identify their initial performance before the intervention. The test lasted for 50 minutes. A Pre-Intervention Questionnaire (PIQ-1) was also administered to identify the difficulties students were facing on learning hybridization and molecular shapes. The difficulties identified helped in the development of the intervention strategy. The participants were engaged for four weeks, by using computerized video animations and 3D models to address their difficulties. After the implementation of the intervention, another Hybridization Performance Test (HPT-2) which served as a post-intervention test was administered. It also lasted for 50 minutes. Post Intervention Questionnaire (PIQ-2) was also conducted on the same day, to determine the students' views about the new teaching approach. The tests were scored, recorded and subjected to analysis.

3.9 Pre-intervention Activities

The researcher sought permission from the Assistant Headmaster Academic of Anlo Senior High School to conduct a study using the General Science 2B class. The researcher submitted an introductory letter to the Assistant Headmaster Academics in order to be permitted to undertake the study. After permission was granted, the researcher met the thirty participants and briefed them on the purpose, and relevance of the study to them, as well as how the new teaching approach will be used. Students were briefed on the computerized instructional method, and students' concerns were clarified to make them cooperate well in the study. The thirty (30) participants were given serial numbers from 01 to 30. Since there was equal number of male and female students, the females were given odd numbers, whereas the males were given even numbers. They were informed to use the serial numbers given in place of their names in all documents they would present in the study period. After two days, the researcher administered the pre-intervention test (HPT-1) to the students. The test was completed in 50 minutes, then, the test papers were collected from all the 30 participants. The students were allowed to rest for 10 minutes, after which Pre-Intervention Questionnaire (PIQ-1) was also administered. The PIQ-1 was completed after 30 minutes, and the papers were taken from them. The students were informed to prepare for the study process the following week. The HPT-1 was marked over 30 and scores recorded. Marking scheme for HPT-1 is at Appendix E. Students' scores on the pre-intervention test (HPT-1) provided data on the students' performance before the intervention. In addition, the researcher analyzed the students' responses to the Pre-Intervention Questionnaire to identify challenges students were facing in learning hybridization and molecular shapes. The researcher spent three days going through the students' pre-intervention test (HPT-1) and Pre-Intervention Questionnaire (PIQ-1). This process helped the researcher to identify areas the students needed more attention, so that these areas could be addressed during the intervention period.

3.9.1 Design of the computerized instructional package

The computerized video animations and models used in implementing the intervention were videos downloaded from YouTube. Three videos were downloaded and used for the intervention. The first video was titled, "Hybridization theory". This is available at https://www.youtube.com/watch?v=wPw_LCmyjnI. The second video was titled "Types of hybridization in organic compounds". This video is also available at https://www.youtube.com/watch?v=LJfcH81QX5k. The last video was titled "Molecular geometry", which is available at https://www.youtube.com/watch?v=Moj85zwdULg.

The lessons in which each video was used have been captured in the next section. Concrete three-dimensional (3D) models used were ball-and-stick plastic models from polystyrene.

3.10 Implementation of the Intervention

This section outlines the various activities undertaken during the intervention period. Four weeks were used for implementing the intervention. During this period, computerized video animations and 3D models were used as instructional approach to teach seven sub-topics under hybridization and molecular shapes. The sub-topics covered were; hybridization of atomic orbitals; formation of sp^3, sp^2, and sp hybrid orbitals; determination of hybridization state; formation of sigma and pi bonds; determination of molecular shapes; construction of molecular shapes in three-dimensions (3D) using ball-and-stick models; and sketching of molecular shapes. They were covered in seven different lessons in a period of four weeks. There were two periods allocated for chemistry on the school time table. Each period was a double period which lasted for two hours. Therefore, two lessons were taught in a week. After delivery of each topic, the animated videos were shared to students with personal laptops. The videos were also shared and saved on the computers in the school laboratory, which allowed students to access them at their leisure time. The next section presents details of the lessons taught using the computerized video animations and models. Appendix H shows a scheme of work prepared by the researcher that provides details of the systematic activities on each lesson.

3.10.1 Lesson 1: Hybridization of Atomic Orbitals

The researcher prepared the classroom by setting up the laptop, projector, and the speaker. The lesson started with full revision on covalent bond, since it was going to form a relevant previous knowledge (RPK) for the new lesson. The researcher explained covalent bond as a type of chemical bond which involves the sharing of electron-pair by two atoms. For example, in the formation of hydrogen molecule (H_2), each hydrogen atom contributes one electron to be shared by the two. This makes each hydrogen attain two electrons, and for that matter become stable. Formation of covalent bonds in compounds like HCl, CH_4, and CO_2 were discussed. The researcher asked the students to think about what happened to the molecules before they involve in the bonding process. The researcher briefly explained that, atomic orbitals mix to give new set of hybrid orbitals before they overlap to form a bond. This concept of mixing of atomic orbitals in preparation for bonding is known as hybridization. This initiated the class into the concept of hybridization. The researcher then introduced the topic; "Hybridization of atomic orbitals". He explained hybridization as the mixing of atomic orbitals of different energies and shapes in an atom, to form a new hybrid orbital. The researcher went on to show the video animation on hybridization. The video was titled "Hybridization theory". In the video, carbon atom was used as a case study. The video showed the ground state valence shell electron configuration of carbon; $2s^2$, $2px^1$, $2py^1$, showing the presence of two unpaired electron. However, the stable compound of carbon must have four bonds. This brought into mind the concept of hybridization. The video animation continued to show the excited state configuration of carbon, by slowly moving one electron from the 2s orbital into the empty 2pz orbital. This showed four unpaired electrons in the valence shell. It then showed the 3D shapes of the spherical 2s, dumb-bell shapes of 2px, 2py and 2pz orbitals respectively. The video showed the mixing of the four orbitals to generate four sp^3 hybrid orbitals, showing the way the carbon atom arranges its orbitals in preparation for bonding. Interestingly, the students were like "waaooo" waaooo", and some were clapping and nodding their heads in agreement to the concept. They got to visualize the concept of hybridization, and noted that it occurs in the orbitals of the same atom, as well as orbitals of same energy level. They saw for themselves how the orbitals of different orientations and energies mix to form new hybrid orbitals. Figure 14 shows a screenshot of a 3D structures of four sp^3 hybrid orbitals.

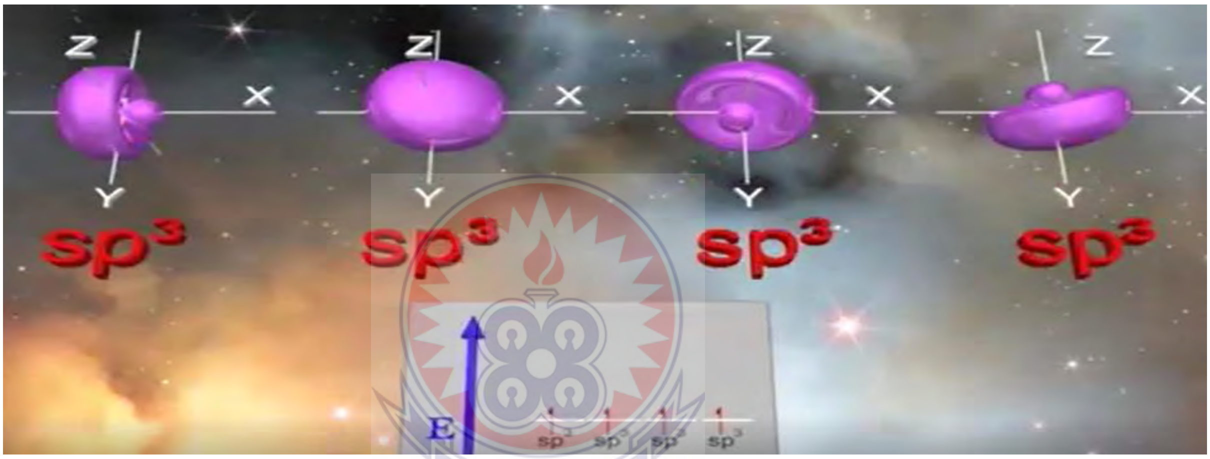

Figure 14: Screenshot of video showing the 3D structures of four sp^3 hybrid orbitals

The researcher closed the lesson by allowing students discuss some practice questions prepared by the researcher. After the discussion, students were informed to read on formation of hybrid orbitals before coming to class for the next lesson.

3.10.2 Lesson 2: Formation of sp^3, sp^2, and sp hybrid orbitals

The researcher did a short revision with the students on what was learnt during the previous meeting through questioning and answering. The researcher then based on the previous discussion to introduce the next lesson for the day. He explained hybrid orbital as atomic orbital formed when two or more different orbitals of the same atom mix. The orbitals involved come from the same energy level. The number of orbitals formed determine the total hybrid orbital formed. The researcher then projected the video animation which showed the formation of sp^3, sp^2 and sp hybrid orbitals. The video animation started with the sp^3 hybridization, it presented the three-dimensional animations of s, px, py, and pz orbitals. It showed the mixing of the s, px, py, and pz orbitals to generate four sp^3 hybrid orbitals. The video animation showed the position of the unpaired electron in each hybrid orbital clearly separated at an angle of 109.5°, and ready for bonding. The display on the animation attracted a lot of attention and the class became very lovely. It continued by bringing the s-orbital of four hydrogen atoms, which overlapped axially with the four sp^3 hybrid orbitals, to form CH_4 molecule.

The video animation continued to show the formation of sp^2 hybrid orbital, using the same carbon atom as example. At this point, only the 2s, 2px, and 2py mixed to generate $3sp^2$ hybrid orbital. At this point, students were consciously waiting for where the 2pz -orbital will be, and so the researcher paused the video to allow some thinking. After five minutes, the video continued to show the gradual mixing of the three sp^2 hybrid orbital and the unhybridized 2pz orbital, which showed the three-dimensional structure of the unhybridized 2pz orbital with its lobes disposed above and below the hybridized carbon atom. Screenshot of this is shown at Figure 15. Almost every student started clapping for some time. The video animation continued to show the formation of the sp hybrid orbital. At this point, students saw for themselves how the orbitals orient themselves in the formation of sp^3, sp^2, and sp hybrid orbitals. A screenshot showing the mixing of $3sp^2$ and unhybridized 2pz orbital of carbon is shown at Figure 15.

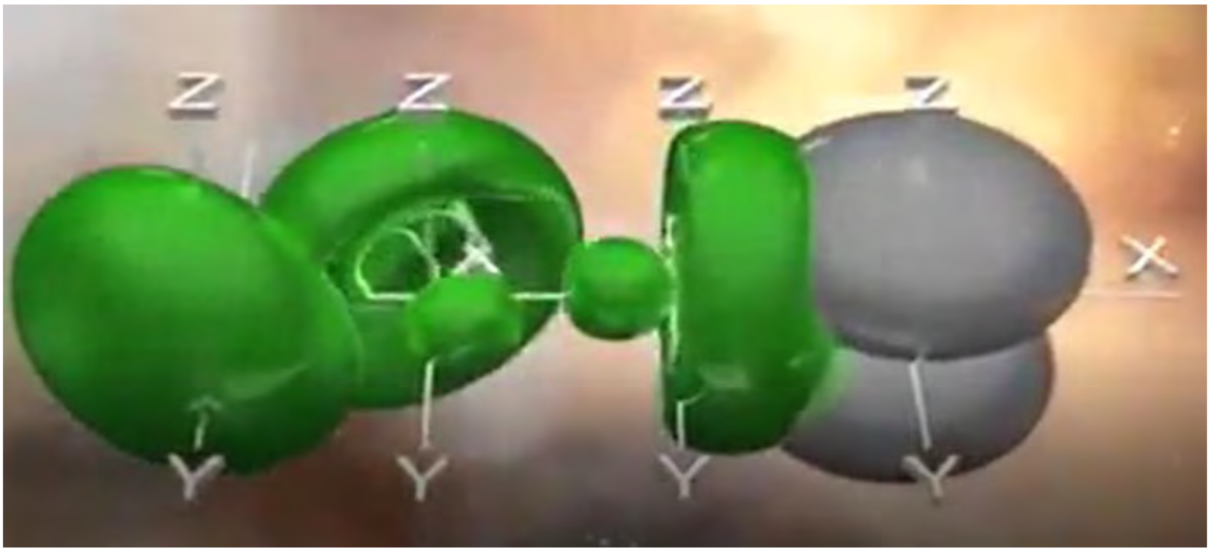

Figure 15: Screenshot showing the mixing of $3sp^2$ and the unhybridized 2pz orbital of carbon

3.10.3 Lesson 3: Determination of hybridization state

As usual, a short revision was conducted on what was taught the previous meeting. The researcher also revised the students' prior knowledge on writing Lewis' structures of molecules followed by identifying the number of electron-groups around each atom. After the revision, the researcher introduced the day's lesson, by showing the continuation of the same video animation titled "Hybridization theory". The video showed several molecules with and without lone-pairs, and explained how the VSEPR theory could be used to determine the hybridization state of the central atoms in each molecule. The researcher paused the video for some time, and allowed the students to determine hybridization states of central atoms in subsequent molecules before they watched the final solutions. Students exhibited higher level of participation in the process. The researcher then summarized all that they watched. It was emphasized that, whether single, double or triple bond, it is counted as one group, a lone-pair is also counted as one group. The number of electron-groups represent the hybridization state of the atom. Two electron-groups around an atom represent sp, three electron-groups represent sp^2, and four electron-groups represent sp^3 hybridization respectively.

After the summary, the students were then put into six groups, with each group comprising five members. The computerized package showed series of molecules which the researcher made the students to cooperate with themselves and determine the type of hybridization exhibited by some atoms in those molecules. The video displayed six big structures in which the researcher asked the groups to determine the hybridization states of some atoms. Five minutes was allowed for the members of each group to interact and put down their answers, followed by watching the video to confirm the answers before moving to the next molecule. This enhanced cooperative learning among the students. The researcher summarized the lesson by discussing the solutions with the students. Screenshot of some molecules in the video is shown at Figure 16.

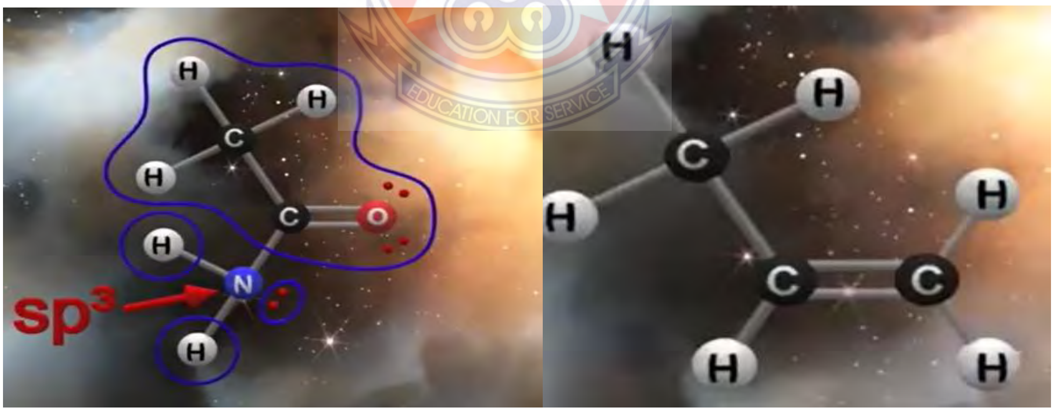

Figure 16: Screenshot of some molecules in the video students discussed in their groups

3.10.4 Lesson 4: Formation of sigma and pi bonds

The researcher introduced the lesson by asking what students know about single and multiple bonds. Through the discussions, the researcher introduced the day's topic.

The researcher showed the video animation on this lesson, which was titled "Types of hybridization in organic compound". The video explained the formation of sigma and pi bonds (double and triple bonds) using ethane, ethene, and ethyne. The video clearly showed the 3D shapes, and the inter-nuclear axis responsible for sigma bond formation. In forming sigma bond, it showed the axial or head-to-head overlap of the two sp^2 hybrid orbitals of two carbon atoms at their internuclear axis. It also showed the lateral overlap of the remaining unhybridized pz orbitals of each carbon, which formed a pi bond. This indicated two bonds; one sigma and one pi. The video continued to show the formation of sigma and pi bonds in ethyne, which also displayed the head-on overlap, as well as lateral overlap of two p orbitals of one carbon, with two p-orbitals of another carbon, resulting in triple bond. At this point, the researcher observed that students were building mental pictures they never had access to. The video animation rotated the 3D structure of ethene showing the bonds below and above the plane. Students were very happy and active, especially when the overlapping were occurring. At this point, students understood that, single bonds are sigma bonds, in a double bond; there is one sigma and one pi bond. In a triple bond, there is one sigma bond and two pi bonds. Screenshot of video animation showing axial and lateral overlap of atomic orbitals is at Figure 17.

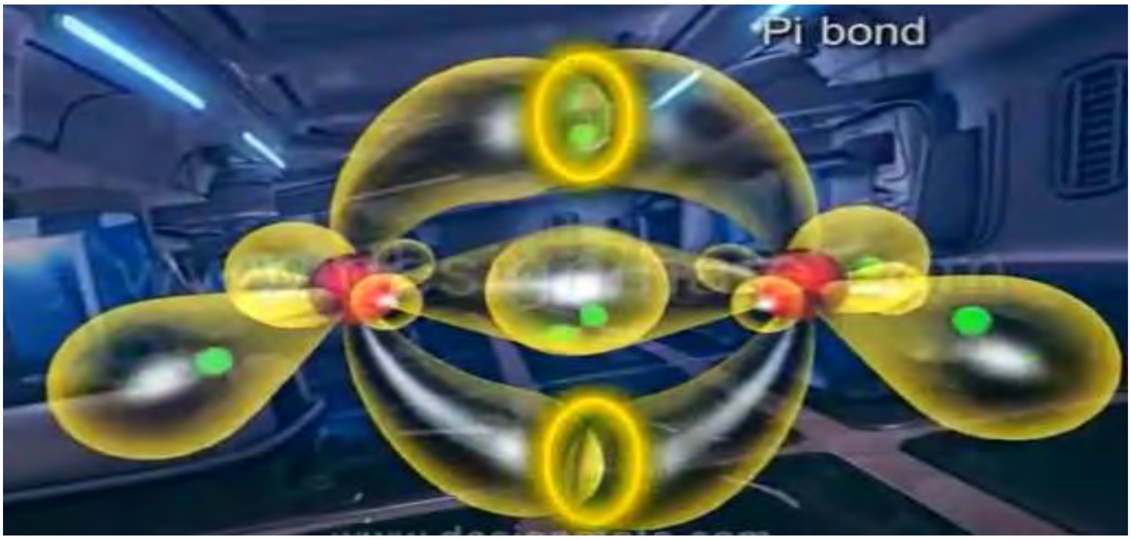

Figure 17: Screenshot of video animation showing axial and lateral overlap of atomic orbitals resulting in sigma and pi bonds

After watching the video, the researcher wrote structures of some molecules on the board, and asked students to identify the number of sigma and pi bonds present in each. The molecules include structures of butane, but-2-ene, propanoic acid, pentanol and propene. After 10 minutes trial, the researcher discussed the questions with the students, and brought the lesson to a close.

3.10.5 Lesson 5: Determination of molecular shapes

At this point, students already knew about determining electron group around a central atom, therefore a ten minutes revision was conducted. The researcher introduced the day's lesson, by allowing students watch the video animation on molecular shapes, titled "Molecular geometry- rules, examples and practice". The video focused on the steric number of each molecule; which is the number of bonded atoms and lone-pairs around the central atom. The video outlined the steps involved in determining the shape of a given molecule, which is summarized in Appendix G. The video showed the effect of lone-pairs, by displaying the repulsions responsible for changing the bond angle and shape of a given molecule. Students were very attentive, as they developed interest in how the bonded pairs as well as the lone-pairs were repelling each other. Attention was given to how the lone-pairs affect the bond angle and shapes of the molecules. At this point, the video animation provided practice examples for students to determine the shapes of BF_3, N_2, H_2S, PH_3, HCN and CF_4. Students showed high level of understanding on the trial work, especially the effects of lone-pairs on the shapes of H_2S and PH_3. This was an indication that, the video animation and model package was improving their conceptual visualization and understanding. In summary, students were guided to focus on only bonded electron-pairs to determine the shapes of molecules. The researcher explained that, the number of electron-groups help to determine the electron group geometry, whereas the bonded groups help to determine the molecular geometry or shape. However, it is important to consider the lone-pairs, because they have effect on the shape and bond angle of the molecule. Figure 18 is a screenshot of video showing the effect of lone-pairs on two molecules with four electron-groups.

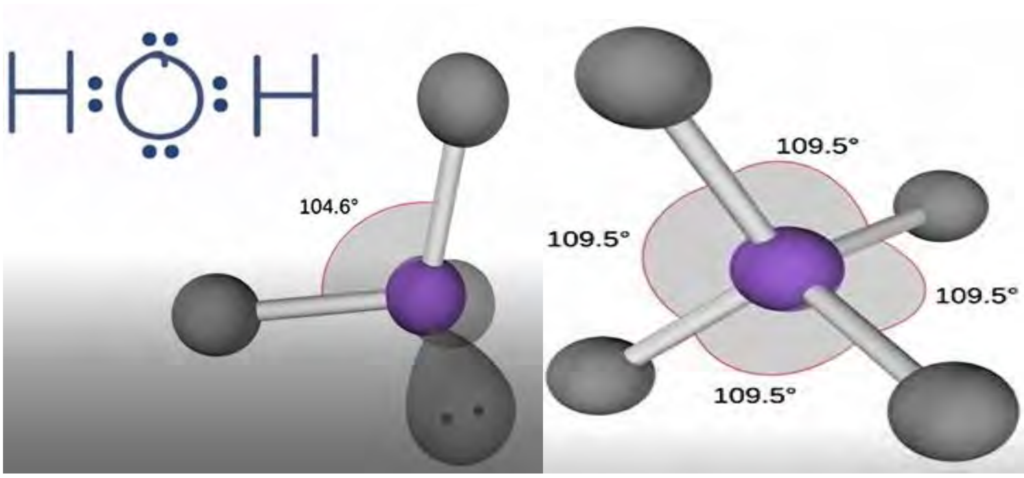

Figure 18: Screenshot of video showing the effect of lone-pairs on two molecules with four electron-groups.

3.10.6 Lesson 6: Construction of molecular shapes in three-dimensions (3D) using ball-and-stick models

This was hands-on cooperative lesson taught. The researcher started the lesson by asking the students to be in their groups as done in the previous lessons. There were six groups in all, with five members each. Each group was given a set of molecular kits with ball-and-stick models. The researcher projected series of molecules for students to construct their shapes using the molecular models. They were asked to construct molecular shapes for molecules like CH_4, NH_3, H_2O, $CH_3CH_2CH_2CH_3$, C_2H_4, and C_2H_2. Shapes constructed include linear, tetrahedral, trigonal planar, trigonal pyramidal, bent or V-shape. This helped the students to navigate between 2D and 3D representations. Converting molecules in 2D representation to 3D representations using the molecular kit models helped them develop their spatial skills significantly. Furthermore, the researcher asked group members to cooperate and construct 3D shapes of molecules they want using the ball-and-stick models. In fact, some groups constructed various kinds of big structures the researcher never imagined they could. This made students motivated to learn more, making the class very interesting. Figure 19 is a sample picture showing teacher monitoring students' progress on working with ball-and-stick models.

Figure 19: Picture of teacher monitoring students using ball-and-stick models

3.10.7 Lesson 7: Sketching of molecular shapes

The researcher started the lesson by asking students to be in their groups of 5 members. Each group was given molecular kits with ball-and-stick models. The researcher projected the video animation on molecular geometry, and asked the groups to construct shapes of molecules displayed in the video, as they did during the last lesson. Molecules they constructed include CH_4, NH_3, H_2O, SO_2, $CH_3CH_2CH_2CH_3$, C_2H_4, and C_2H_2. After constructing each molecule, the researcher guided them to sketch the shapes in their notebooks using wedge-dash-line structures. The researcher moved onto the next activity by writing 2D representations of some molecules on the board, and guided the students to sketch the molecules in 3D representations using wedge-dash-line structures. In the process, they were guided to identify the hybridization state of each atom, which would help them predict the correct 3D shapes. Students with challenges were assisted by their colleagues and the researcher whenever the need arose. A sample of 3D wedge-dash-line structure sketched by one group is shown at Figure 20.

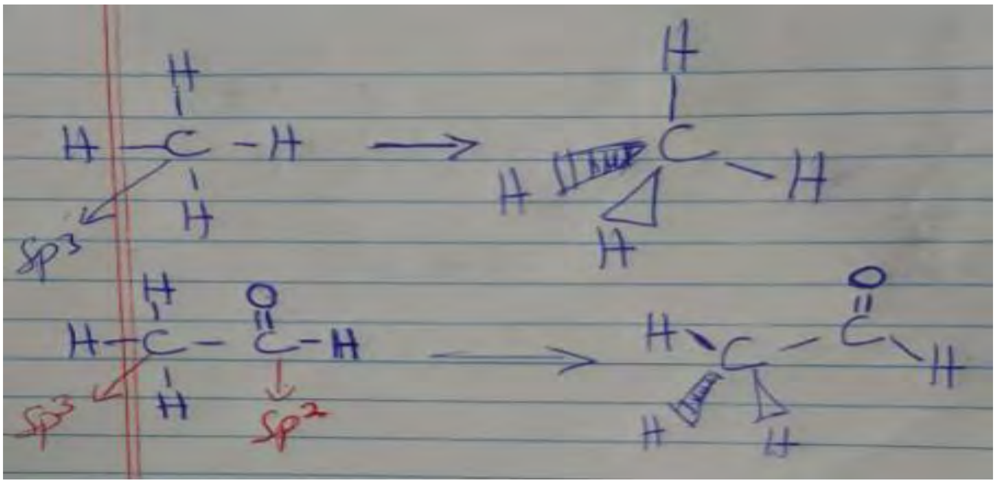

Figure 20: A 3D wedge-dash-line structure sketched by one of the groups

The researcher ended the lesson, motivated the students for being discipline. He then asked them to prepare for a post-intervention test on what has been taught.

3.11 Post-intervention Activities

After three days of implementing the intervention, a post-intervention test (HPT-2) was conducted (see Appendix B). The HPT-2 test lasted for 50 minutes, and the papers were taken from the students. After 5 minutes on the same day, Post Intervention Questionnaire (PIQ-2) (see Appendix D) was also administered, which also lasted for 30 minutes. Marking scheme for HPT-2 is shown at Appendix F.

3.12 Data Analysis

Scores from the two Hybridization Performance Tests (HPT-1 and HPT-2) were organized and analyzed with paired sample t-test using Microsoft Office Excel 2019 to identify if there was significant difference in performance between the two tests. Cohen's d was calculated to determine the effect size of the intervention on the students' performance. Also, scores in the HPT-2 were analyzed with unpaired sample t-test using Microsoft Office Excel 2019 to identify if there was a differential mean performance between male and female students exposed to computerized animations and model instructional approach. Data from the Pre-Intervention Questionnaire (PIQ-1) and Post Intervention Questionnaire (PIQ-2) were organized and analyzed using descriptive statistics involving percentages. Research question 1 was answered with data from PIQ-1. Research question 2 was answered with data from HPT-1 and HPT-2. Research question 3 was answered using data from HPT-2. The fourth research question was answered using data from PIQ-2.

3.13 Ethical Considerations

Ethical standards were upheld throughout the study. Though the researcher was a teacher in the school under study, he sought permission from the Assistant Headmaster Academics before undertaking the study. In addition, the researcher sought the consent of the participants in the study, as well as those present in the picture at Figure 19 of this study. Furthermore, the participants were given serial numbers ranging from 01 to 30, which were used in place of students' names during the administration of any research tool. Based on this strategy, the participants were very sure of confidentiality and anonymity in providing honest information for the study.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Overview

This chapter contains the results and discussion of the findings in this study. The purpose of the study was to improve students' performance in hybridization and molecular shapes using computerized animations and models. It also presented the mean difference in performance between male and female students exposed to computerized animations and models. The results and discussion are presented in the order of the research questions.

4.1 Presentation of the Study Results According to the Research Questions

Research question 1: What are the difficulties students faced during lessons on hybridization and molecular shapes?

To answer research question 1, eighteen (18) items were structured to solicit information from the participants on the difficulties they faced during lessons on hybridization and molecular shapes. Students' responses obtained are presented in Table 1.

Table 1: Percentage of Students that Faced Difficulties

Item	Number of students with difficulty (n= 30)	Percentage (%) of students with difficulty
1	7	23.3
2	13	43.3
3	19	63.3
4	21	70.0
5	2	6.7
6	14	46.7
7	18	60.0
8	13	43.3
9	30	100
10	22	73.0
11	28	93.3
12	26	86.7
13	20	66.7
14	15	50.0
15	23	76.7
16	20	66.7
17	3	10.0
18	19	63.3

Source: Field Survey, 2023

Items 1 to 11 in Table 1 were structured to determine the difficulties students were facing during lessons on hybridization of atomic orbitals. In addition, difficulties faced by the students on lessons involving molecular shapes were identified with items 12 to 18. The responses obtained from the participants in Table 1, confirmed that they had difficulties in learning hybridization and molecular shapes.

Research Question 2: What would be the effect of computerized animations and models (CAM) on students' performance in hybridization and molecular shapes?

This research question was formulated into null hypothesis which was tested to provide answer to the research question. The null hypothesis was stated as;

Ho2: Computerized animations and models have no significant effect on students' performance in hybridization and molecular shapes.

To determine the effect of computerized animations and models (CAM) on students' performance, pre-intervention test (HPT-1) was administered to collect data on students' performance before the intervention. A post-intervention test (HPT-2) was also administered to collect data on the students' performance after the intervention. Students' scores on both tests were obtained and subjected to statistical analysis involving t-test at 0.05 level of significance using Microsoft Excel version 2019. The result is presented in Table 2.

Table 2: Paired Sample t-test Analysis of Students' Performance Scores in Pre-intervention and Post-intervention tests.

Test	N	Mean	SD	df	t-value		p-value
					tstat	tcrit	
Pre-intervention	30	13.33	4.27	29	-16.199	-2.045	0.000*
Post-intervention	30	21.93	4.73				

Table 2 reveals that, the P-value was less than the alpha value ($P < 0.05$). Therefore, the null hypothesis was rejected. Also, the students' pre-intervention test and post-intervention test means scores were 13.33 and 21.93 respectively, representing a mean difference of 8.6. This indicates that, the students' pre-intervention test and post-intervention test means scores differed significantly. Moreover, to determine the effect size, the researcher calculated the Cohen's d as shown in Table 3.

Table 3: Cohen's d result

Test	Mean	SD	Cohen d
Pre-intervention	13.33	4.27	1.9
Post-intervention	21.93	4.73	

Research Question 3: What is the differential effect of computerized animations and models (CAM) on the male and female students' performance after the intervention?

This research question was also formulated into null hypothesis which was tested to provide answer to the research question. The null hypothesis was stated as;

Ho3: There is no significant difference in the mean performance of male and female students after the intervention.

To test this hypothesis, male and female students' scores on the post-intervention test were obtained and subjected to statistical analysis involving t-test at 0.05 level of significance using Microsoft Excel version 2019. The result is presented in Table 4.

Table 4: Unpaired Sample t-test Analysis of Male and Female Students' Performance Scores in the Post-intervention Test

Student Sex	N	Mean	SD	df	t-value		p-value
					tstat	tcrit	
Male	15	23.80	4.14	28	2.256	2.048	0.032
Female	15	20.33	4.27				

Table 4 reveals that, the P-value was less than the alpha value ($P < 0.05$). Therefore, the null hypothesis was rejected. In addition, the post-intervention mean score of male students was 23.80, whereas that of the females was 20.33, representing a mean difference of 3.47, in favour of the male students.

Research Question 4: What are the views of students on the integration of CAM in the teaching and learning of hybridization and molecular shapes?

The views of the students helped to reveal their perceptions of the CAM after it was used in the teaching and learning process. Eighteen item statements were used to ascertain the students' views towards CAM. These items were structured to gather students' views on CAM under the following;

1. CAM on abstract learning
2. Students' conceptual understanding, spatial ability and performance

3. The extent to which CAM affected their interest and motivation.
4. Nature of CAM instruction
5. Barriers to CAM integration and usage.

Students' responses on the items were analyzed and presented as shown in Table 5.

Table 5: Students' Views Towards CAM Integration

Item	Strongly Agree (SA)	Agree (A)	Uncertain (U)	Disagree (D)	Strongly Disagree (SD)
1	16 (53.3%)	8 (26.7%)	3 (10%)	2 (6.7%)	1 (3.3%)
2	18 (60%)	6 (20%)	1 (3.3%)	3 (10%)	2 (6.7%)
3	21 (70%)	2 (6.7%)	0 (0%)	2 (6.7%)	5 (16.7%)
4	15 (50%)	6 (20%)	4 (13.3%)	4 (13.3%)	1 (3.3%)
5	0 (0%)	2 (6.7%)	3 (10%)	6 (20%)	19 (63.3%)
6	17 (56.7%)	8 (26.7%)	1 (3.3%)	3 (10%)	1 (3.3%)
7	19 (63.3%)	6 (20%)	3 (10%)	2 (6.7%)	0 (0%)
8	18 (60%)	5 (16.7%)	2 (6.7%)	5 (16.7%)	0 (0%)
9	21 (70%)	5 (16.7%)	1 (3.3%)	3 (10%)	0 (0%)
10	14 (46.7%)	8 (26.7%)	4 (13.3%)	3 (10%)	1 (3.3%)
11	10 (33.3%)	7 (23.3%)	8 (26.7%)	2 (6.7%)	3 (10%)
12	13 (43.3%)	8 (26.7%)	1 (3.3%)	3 (10%)	5 (16.7%)
13	1 (3.3%)	3 (10%)	4 (13.3%)	6 (20%)	16 (53.3%)
14	16 (53.3%)	9 (30%)	2 (6.7%)	2 (6.7%)	1 (3.3%)
15	9 (30%)	7 (23.3%)	6 (20%)	6 (20%)	2 (6.7%)
16	15 (50%)	9 (30%)	6 (20%)	0 (0%)	0 (0%)
17	19 (63.3%)	7 (23.3%)	0 (0%)	1 (3.3%)	3 (10%)
18	12 (40%)	5 (16.7%)	7 (23.3%)	4 (13.3%)	2 (6.7%)

Source: Field Survey, 2023

Items 1, 6, and 8 were structured to gather students' views about CAM effect on abstract learning. Results from students' responses indicate that, CAM improves students' conceptualization of abstract concepts. Items 2, 7, 10 and 12 were structured to focus on the extent of students' conceptual understanding, spatial ability and performance. Students' responses from Table 5 show that, CAM helps simplify concepts, which resulted in enhancing their understanding of hybridization and molecular shapes. Items 3, 4, and 14 focused on students' motivation and interest in chemistry. From Table 5, responses to these items show that, CAM have positive impacts on students' motivation and interest in chemistry. Items 5, 9, 11, and 13 were used to identify students' views on the nature of CAM instructional approach. Students' responses to these items as shown in Table 5 show that, learning with CAM is not boring, however, it enhances active participation and cooperative learning. Items 15, 16, 17 and 18 were structured to gather students' views on barriers to integration of CAM. Majority of the students are of the view that, the key barriers to CAM integration are lack of digital resources, lack of enough skills in using CAM, and insufficient instructional time.

4.2 Discussion of Findings

The research study was specifically designed to employ computerized animations and models to improve chemistry students of Anlo Senior High School performance in hybridization and molecular shapes. To achieve this purpose, four objectives, four research questions and two null hypotheses were formulated. Dependent-samples t-test, independent-samples t-test, and simple percentages were used in analyzing the data of participants and answering the research questions. The first objective was to determine the difficulties students faced during lessons on hybridization and molecular shapes. The responses obtained from the participants in Table 1, confirm that they had difficulties on lessons involving hybridization and molecular shapes. Items 1 to 11 were structured to determine the difficulties students were facing in hybridization of atomic orbitals. Students' responses on these items indicated that, they were indeed lacking visual aids in their learning of hybridization. For instance, 23.3% of the students indicated that they didn't understand how orbitals of different energies and shapes mix to give new hybrid orbitals, and 43.3% claimed they didn't understand 2sp, $3sp^2$, $4sp^3$ hybrid orbitals (item 2). These findings indicate that the students had difficulties with the concept of hybridization itself, and therefore did not understand the meaning of hybridization. These findings are consistent with that of Hanson, Sam and Antwi (2012) who found that only 6.8% of first year undergraduates could give the correct meaning of hybridization, and only 10.3% understood the difference between pure atomic orbitals and hybrid orbitals like 2sp, $3sp^2$ and $3sp^3$. In addition, Cil and Ugras (2015) also found that 59.8% of undergraduate students in Indonesia could not define hybridization correctly. The students defined the concept in four different ways, meanwhile only one of them was correct. These two previous studies associated the students' difficulties to misconceptions they had from their previous studies on hybridization. This is further realized in students' response to item 10 in this study, where majority of the students (73.3%) indicated that they did not know that pi bonds occur in the overlap of only p-orbitals.

From Table 1, 21 students (70%) indicated that they could not visualize how atomic orbitals mix to give hybrid orbitals (item 4). In addition, 28 students representing 93.3% indicated that, they couldn't explain the formation of single, double and triple bonds from atomic and hybrid orbitals (item 11). This was evidenced significantly in their response to item 9, where all the 30 participants (100%) indicated that the concept of hybridization is too abstract. These findings are in line with that of Calis (2018) who reported that the difficulty associated with learning atomic orbitals and hybridization is due to their abstractness. Calis (2018) found among grade 12 high school students in Turkey that, most of the students could not show the correct formation of hybrid orbitals. The students had difficulties explaining the formation of single, double and triple bonds. Additionally, Calis found that students had difficulties in representing the formation of hybrid orbitals schematically. His finding supports that of this study, as 18 students representing 60% indicated in this study that they could not represent by drawing the formation of hybrid orbitals.

Furthermore, 46.7% of the students indicated they experienced difficulties in determining the hybridization state of an atom (item 6), and 43.3% also indicated that they could not describe the formation of sigma and pi bonds (item 8). Findings of this study are parallel with that of Abukari et al. (2022), who investigated among senior high schools' students in Upper West Region of Ghana difficulties in learning hybridization. They found that; students had difficulties in determining the type of hybridization exhibited by the central atoms in molecules such as CO_2, NH_3, BCl_3, $BeCl_2$, C_2H_4 and C_2H_2, students had difficulties in explaining hybrid orbitals concept, they had difficulties in showing the difference between the formation of sigma and pi bonds, and difficulty in explaining the formation of carbon-carbon double and triple bonds in compounds such as ethene and ethyne. All these findings are very consistent with that of the present study.

Items 12 to 18 were also structured to ascertain the difficulties students faced during lessons on molecular shapes. The result showed that 26 students representing 86.7% had difficulty in establishing the difference between electron-pair geometry and molecular geometry (item 12). This means predicting hybridization type for a central atom in a compound was a challenging task. In addition, students' responses to items 13, 14, and 15 indicated that they were not considering the presence of lone-pairs and their effects on molecular shapes and bond angles. Based on these, 63.3% of the students indicated that all molecules whose central atoms exhibit the same hybridization state have the same shape and bond angle (item 18). These difficulties resulted in their inability to predict correct shapes and bond angles of molecules which is evidenced in their response to item 15 in which 76.7% of the students indicated that they cannot predict the correct shapes and bond angles of molecules. Findings of this study are supported by those of Erlina, Enawati and Rahmat (2021) who found that, students struggled to determine the correct shapes of molecules, however, they memorize the shapes of common examples used during the teaching process. The findings of this study are also consistent with that of earlier study by Harrison and Treagust (1996) who found that, students experience difficulties in predicting correct shapes of molecules; 22% of their students thought that repulsion between only lone-pairs of electrons had influence on molecular shapes, and 25% of their students thought that shapes of molecules were affected by repulsion between only bonding pairs electrons around the central atom. Nugraha, Supriada and Fatimah (2018) also found among grade 12 students in Indonesia that, 65% of the students did not understand the influence of lone-pairs on the bond angle and shapes of molecules, and 31% did not understand the various types of geometry forms. Those results are all consistent with findings of this study. Furthermore, findings of this study also agree with Abukari et al. (2022) who found that, senior high school students had difficulties in determining the correct shapes of molecules like CO_2, NH_3, BCl_3, $BeCl_2$, C_2H_4 and C_2H_2, as well as difficulty in using diagrams to represent and explain the shapes of molecules like CO_2 and C_2H_2.

Moreover, 66.7% of the students indicated that they could not sketch the correct shapes of molecules (item 16), whereas 10% indicated they could not sketch the different shapes of s and p atomic orbitals. These results are also consistent with that of Abukari et al. (2022) who found that majority of the students had difficulty in drawing the shapes of s and p orbitals to form sigma and pi bonds, and 71.7% could not sketch to show bonding in ethyne. All these findings align with that of the present study. Based on some of these difficulties chemistry students face, Jones and Kelly (2015) proposed that, in order for students to grasp the ability to predict shapes of molecules correctly, they need to have the ability to visualize molecules. They added that, visualization is a means to improving students understanding of abstract concepts in chemistry, and visualization plays a significant role in understanding the determination of shapes of molecules.

The second objective was to assess the effect of computerized animations and models (CAM) on students' performance in hybridization and molecular shapes. Results of the study showed that, the null hypothesis which was stated as, "Computerized animations and models have no significant effect on students' performance in hybridization and molecular shapes", was rejected. The rejection of the null hypothesis meant that, the use of CAM as instructional approach had a significant effect on students' performance in hybridization and molecular shapes. This was evidenced in the pre-intervention test and post-intervention test mean scores of the students. From Table 2, the students' pre-intervention test and post-intervention test means scores were 13.33 and 21.93 respectively. This showed a significant mean difference of 8.6, indicating that, the students' pre-intervention test and post-intervention test means scores differed significantly. These mean scores also show that the students scored higher in the post-intervention test than they scored in the pre-intervention test; indicating that the use of CAM significantly addressed the students' difficulties identified in the Pre-Intervention Questionnaire (PIQ-1) analyzed in research question one. This higher score also shows that, there was an improvement in students' performance after they were exposed to CAM. Furthermore, Cohen's d was calculated to be 1.9. According to Academic Success Center (2023), the guidelines for interpreting Cohen's d values to determine the degree of effect size are; 0.2, 0.5, and 0.8 indicates small effect, medium effect, and large effect respectively. Therefore, Cohen's d value of 1.9 indicated a very large effect size. This implied that there was a very large effect of computerized animations and models on the students' performance after the intervention. The implication of this finding is that, CAM as instructional approach is very effective in improving students' performance in hybridization and molecular shapes. This finding concurs with that of Ejike and Opara (2021), who found that computerized animated videos significantly improve the performance of students in chemistry. Finding of the study is also in agreement with Yanarates (2022) who found that computerized animation techniques increase students' knowledge level and hence improve their performance. Koomson, Safo-Duku and Antwi (2020) conducted a study in Ghana to investigate the effect of computerized simulation and computerized modelling software on teaching and learning hybridization at the senior high school level. Findings of their study are consistent with that of this present study, since they also found that, computerized modeling software significantly improved the performance of students that were taught using the modeling software than those that were taught using conventional methods. Based on that finding, they recommended that teachers should adopt computerized simulation and computerized modeling software for teaching and learning hybridization at the senior high schools. Findings of the present study support their recommendation. In addition, finding of the study is in line with that of Ishmail et al. (2017); Ikwuka and Samuel (2017); and Nuni et al. (2019), who found that computerized video animations and models as instructional approaches significantly improve students' performance. Moreover, finding of this study is supported by a study conducted by Akilli (2021), which examined the effectiveness of 3D computer models on Turkey undergraduate student teachers' academic achievement and mental model construction. He found that, instructions using 3D computer models significantly improve students' academic achievement and mental model construction. Based on those findings, he concluded that 3D computerized models are very effective tools for better learning and improving students' performance in chemistry. Furthermore, the present study's findings also support the recommendation made by Teplá, Teplý, and Šmejkal (2022), who suggested the incorporation of computerized video animations and 3D models in teaching and learning hybridization and molecular geometry. Their study on the influence of 3D models and animations on students in natural subjects found that, incorporating computerized animations and 3D models highly improved students' performance in natural subjects, especially chemistry.

The third objective was to investigate the differential mean performance of male and female students after they were exposed to CAM. Analysis of the results showed that, the null hypothesis which was stated as, "There is no significant difference in the mean performance of male and female students after the intervention", was rejected. The rejection of the null hypothesis meant that, there was a significant difference in the mean performance of male and female students taught hybridization and molecular shapes using computerized animations and models. This was evidenced in the post-intervention test mean scores of the male and female students. From Table 4, the post-intervention mean score of male students was 23.80, whereas that of the female students was 20.33. This represents a mean difference of 3.47, indicating that, the post-intervention means scores differed significantly in favour of the male students. This also meant that, the performance scores of male students were significantly higher than that of the female students after the intervention. The implication of this finding is that, though teaching hybridization and molecular shapes with computerized animations and models improve the performance of both male and female students, it is more effective among male students than female students. Finding of this study is consistent with that of Ikwuka and Samuel (2017), who experimentally investigated the effect of animations on Nigeria secondary school chemistry students' academic achievement. They found that using computer animations to teach chemistry improved the performance of male students more than their female counterparts. Finding of this study is also in line with that of Opara (2011), Ajaja (2012), Armah, Akayuure and Armah (2021), who found and reported that males perform better than females when exposed to similar methods. However, this finding contradicts with the findings of Chikendu (2018) and Yanarates (2022), who found that computerized animated instruction significantly improves the performance of female students more than their male counterparts in chemistry. Furthermore, the finding of this study also differs from the findings of Gambari, Falode and Adegbenro (2014); Owolabi and Ogini (2014); and Adekunle et al. (2021) who reported that computerized animated instructions and computerized-based simulations improved the performance of male and female students similarly, since they all found no statistical difference between the performance of male and female students exposed to computerized animated or simulation instructions.

The fourth objective was to find out the views of students on the integration of CAM in teaching and learning of hybridization and molecular shapes. Students' responses on the items were analyzed and presented in Table 5. Items 1, 6, and 8 focused on CAM effect on abstract learning. From Table 5, 24 students representing 80% agreed to the assertion that they can visualize the process of hybridization with CAM (item 1). In addition, 25 students representing 83.3% also agreed that CAM helps them to understand the effect of lone-pairs on molecular shapes (item 6). These findings from items 1 and 6 concurred with that of Lasisi et al. (2021), who found that computerized instruction improved students' learning of abstract concepts better than traditional methods. The findings are also in line with the finding of Gambari, Falode and Adegbenro (2014), who conducted a study in Nigeria to investigate the effectiveness of computer animation on junior secondary school students' achievement in mathematics. They found that, computer animations enhance students' ability to visualize 3D objects more effectively. In addition, 23 students representing 76.7% agreed that they can conceptualize the formation of sigma and pi bonds. These findings are consistent with the findings of Kearsley (2002) who found that computer animation facilitated students' encoding process which enhanced conceptualization and visualization of abstract concepts. Furthermore, findings by Nuni et al. (2019) conducted in Kenya to investigate the effectiveness of animated video on secondary school students' conceptualization of electronics are also consistent with the findings of this study. They found that, animated video significantly improved students' conceptualization of abstract concepts since abstract concepts are clearly illustrated in video animations.

Items 2, 7, 10 and 12 were structured to focus on the extent of students' conceptual understanding, spatial ability and performance. From Table 5, 24 students representing 80% agreed that CAM helps to understand concepts better, whereas only 5 students representing 16.7% disagreed (item 2). This is evidenced in students' response to item 7 where 25 students representing 83.3% agreed that they can predict the correct shapes of molecules. Findings of this study are consistent with findings of Ismail et al. (2017) who investigated the use of video animation to enhance imagination and visualization of Malaysia College students in engineering drawing. They found that, computerized video animations increased students' imagination and visualization which decreased students' cognitive load by lowering the total cognitive steps required to complete a given task. They added that, computerized animations increase and strengthen students' understanding in very short time in the course of the learning process, which results in increasing students' performance. This study finding is also in line with that of Yanarates (2022) who proved that visual and multimedia instructions such as computerized animations, 3D models and simulations enhance effective understanding; and permanent learning of chemistry concepts is realized by using computerized animations and visual aids. Furthermore, findings of this study are also supported by findings of Teplá, Teplý, and Šmejkal (2022) who investigated the influence of 3D models and animations on students in natural subjects; biology, chemistry and geology. They reported that, incorporating computerized animations and models significantly enhanced understanding and improve performance because they simplify abstract processes. This encourages students to develop interest and decide to study the subject matter at higher levels. Teplá, Teplý, and Šmejkal (2022) further found that, as 3D models demand lower level of visual orientation from students, whereas animations enhance understanding of abstract concepts. Therefore, a combination of the two (animations and 3D models) significantly enhance understanding of subject matter and significantly improve performance. These findings by previous studies indicate that, findings of the present study are accurate.

In addition, 21 students representing 70% agreed that they could convert 2D structures into 3D structures after the intervention. This implies that, the students' ability to rotate 2D and 3D images through cognitive operations improved significantly. This shows an improvement in the aspect of spatial ability called spatial relation. The significant performance in spatial ability indicated that, the students were able to imagine the rotation of 2D and 3D objects through cognitive structures, which was also reported by Bodner and Guay (1997). This result is also consistent with other studies (Akilli, 2021; Rahmawati, Dianhar & Arifin, 2021;) that reported that 3D models and virtual representations enhance students' spatial abilities. Rahmawati, Dianhar and Arifin (2021) analyzed students' spatial ability of molecular geometry using 3D virtual representations, and found that students' performance on spatial relationship involving mental rotation of 2D and 3D objects was 77.94% which was very high compared to the other aspects of spatial abilities.

Items 3, 4, and 14 focused on students' motivation and interest in chemistry. From Table 5, responses to item 3 showed that, 76.7% agreed that learning with CAM is enjoyable. This finding is supported by that of Antwi, Anderson, and Sakyi (2015) who found that students enjoy lessons with computerized packages, which result in motivating them to develop positive interest in the subject matter and encourage them to participate actively in lessons. They associated these findings to the practical and interactive nature of lessons designed with computerized packages. In addition, 21 students representing 70% agreed that learning with CAM increases their interest in chemistry (Item 4). This is evidenced in their response to item 14, in which 25 students representing 83.3% agreed that they wish other topics are taught with CAM.

These findings indicates that, computerized animations and models increased the students' motivation and interest in chemistry. These findings align with the findings of Ismail et al. (2017) who posited that video animation ability to combine multi-visuals effectively enhance students' understanding and increase their motivation, and therefore make learning more interesting. The findings of this study are also parallel with the findings of Koomson, Safo-Adu and Antwi (2020); Nsabayezu et al. (2022); Teplá, Teplý, and Šmejkal (2022). Koomson, Safo-Adu and Antwi (2020) found that, computerized packages are very powerful tools that keep students active, motivated and significantly improves their grasp of chemistry concepts. Nsabayezu et al.'s (2022) findings reported in their study that investigated the impact of computerized based simulations on Rwanda chemistry students in learning organic chemistry, also support the findings of the present study. They found that, computerized simulations were very influential that significantly boost students' self-confidence, motivation and interest. Teplá, Teplý, and Šmejkal (2022) also found that, students find animations and models very entertaining, attractive and interesting. These qualities make computerized animations and 3D models have more positive impacts on students' intrinsic motivation, which make students highly motivated and even develop interest in pursuing chemistry at the tertiary level. All these earlier findings support the findings of the present study.

Students' views on the nature of CAM instructional approach were identified from items 5, 9, 11, and 13. From Table 5, 25 students representing 83.33% disagreed with the statement that learning with CAM is boring (item 5). In fact, 63.33% strongly disagreed with that statement. This finding is also evidenced in students' response in items 9, 11, and 13. For instance, 26 students representing 86.7% agreed that CAM helps them participate actively in teaching and learning process (item 9). In addition, 53.3% of the students strongly disagreed with the statement that CAM makes learning difficult. These findings imply that learning with CAM enhance active students' participation, learning with CAM is not boring, and CAM makes learning easy. Findings of this study are supported by earlier study by Liu and Elms (2019), who found that integration of technological tools in teaching and learning actively engage students in the process, and never make students bored. This finding is further evidenced in students' response to item 11, where more than half of the students (56.7%) agreed that they learn from one another. This finding implies that learning with CAM is also effective in a cooperative environment, which is consistent with finding of Koomson, Safo-Adu and Antwi (2020), who found that computerized packages significantly improve students' performance in hybridization in a cooperative learning environment.

Items 15, 16, 17 and 18 were structured to gather students' views on barriers to integration of CAM. More than half of the students (53.3%) agreed that they lack enough skills in the usage of CAM. This becomes a barrier for students to learn with technological devices. This finding is in line with the findings of Bingimals (2018), who reported that lack of technical support for teachers and students is a major barrier to ICT integration in teaching and learning. Furthermore, 86.7% agreed that their school lacks enough digital resources to support CAM instructions. In addition, 56.7% agreed that instruction with CAM is time consuming. These findings indicate that, majority of the students agreed that, major barriers impeding CAM integration are lack of digital resources, lack of enough skills and insufficient instructional time. Becta (2004) proposed two categories of barriers; school level and teacher level barriers. He classified lack of digital resources and lack of instructional time as school level barriers; and lack of preparation time as teacher level barriers. Those findings align with the findings of this study. These findings are also consistent with the findings of Pelgrum (2001), Dang (2011), Bingimals (2018), and Talan (2021). Dang (2011) found that, the use of ICT tools in lesson preparation is time consuming, which poses a lot of challenges to teachers during lesson preparation or delivery. These make teachers resort to their old instructional methods (Jones, 2001).

Irrespective of the barriers, students' view remains that CAM must be integrated into chemistry instructions. This is clear from their response to item 16, where majority of the students (80%) agreed that CAM must be integrated into teaching and learning of chemistry. This finding implies that students prefer chemistry instructions to be taught using computerized animations and model instructional packages. This is further observed in their response to item 14; in which 83.3% agreed that they wish other topics are taught with CAM. From the analysis, it could be generalized that the students had positive views about the integration of CAM in teaching and learning. This implies that, the use of CAM affected them positively, which suggests that CAM must be encouraged and integrated in schools' instructional activities to improve the quality of teaching and learning of chemistry.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.0 Overview

This chapter presents the summary of the major findings, conclusions and recommendations. It also presents the conclusion made on the findings of the study, recommendations that can help improve the teaching and learning of chemistry, as well as suggestions for further studies.

5.1 Summary of the Major Findings

On difficulties students faced in learning hybridization and molecular shapes, the findings show that students lacked conceptual understanding of hybridization, formation of hybrid orbitals. Also, majority of the students had difficulty with visualizing the mixing of atomic orbitals, and therefore could not describe the formation of sigma and pi bonds. In addition, students had difficulty representing hybrid orbitals by drawing. Majority of the students had difficulties explaining the formation of single, double and triple bonds. Students did not know the difference between electron-pair geometry and molecular shape, and so they were not considering lone-pairs when determining molecular shapes. Students considered molecules whose central atoms exhibit the same hybridization type to have the same shape. Furthermore, students did not know the effects of lone-pairs on molecular shapes and bond angles. All these indicate that, the students lacked visual aids in learning hybridization and molecular shapes. This was evidenced in the results, in which all the participants indicated that the concept of hybridization is too abstract.

Regarding the effect of CAM on students' performance in hybridization and molecular shapes, the study revealed that there was a significant improvement in students' performance after the intervention. The effect of the intervention on the students' performance was very large.

On the differential effect of CAM on male and female students' performance after the intervention, the study results showed that, the mean performance score of male students was significantly higher than that of the female students. This indicates that, CAM as instructional approach improved the performance of the male students than their female counterparts.

Findings from students' views on integration of CAM in teaching and learning of hybridization and molecular shapes showed that; CAM improved the conceptual understanding of abstract concepts, improved students' ability to convert 2D structures to 3D structures, enhanced students' imagination and visualization which reduced students' cognitive load. CAM made learning more enjoyable, students' interest and motivation to learn were increased. Students' views on barriers to CAM integration in teaching and learning are lack of digital resources, lack of enough skills in using CAM, and lack of enough instructional time.

5.2 Conclusions

After analyzing the data, it was found that majority of the students had gross difficulties during lessons on hybridization and molecular shapes. The difficulties included; lack of conceptual understanding of hybridization, inability to describe the formation of hybrid orbitals, difficulty in the determination of hybridization state or type, difficulty in describing the formation of sigma and pi bonds, difficulty in predicting the correct shapes of molecules, and inability to visualize and sketch molecular shapes. The findings also revealed a significant improvement in students' performance after they were exposed to CAM, this shows that CAM as instructional approach is very effective in improving students' performance in hybridization and molecular shapes. This also implies CAM has positive effect on students' performance. Furthermore, the study showed that though CAM improved the performance of both male and female students, the performance of male students was higher than female students. This implies that, CAM was more effective in improving male students' performance than female students.

Moreover, students' views on integration of CAM showed that, it has positive effect on the students. It was found that, CAM enhances the conceptual understanding of abstract concepts, improves students' spatial abilities, enhances students' imagination, visualization and reduces cognitive load. CAM increases students' interest and motivation to learn more. Students are of the view that, the major barriers to the integration of CAM in teaching and learning are lack of digital resources, lack of skills, and lack of enough instructional time.

5.3 Recommendations

Based on the findings of this research, the researcher recommends that:

1. Chemistry teachers of Anlo SHS should integrate CAM in teaching and learning of hybridization and molecular shapes. This would help enhance students understanding and improve their performance.
2. Chemistry teachers and students at Anlo Senior High School should be trained in the effective utilization of computerized packages in teaching and learning of chemistry.
3. The Ministry of Education, Ghana Education Service and other educational stakeholders must provide digital resources such as computers, projectors, free internet access, for the effective teaching and learning of chemistry at Anlo SHS.

5.4 Suggestions for Further Studies

Based on the findings of the study, the researcher suggests the following arears for further study:

1. Further research studies should be carried out in other senior high schools in Ghana to examine the differential effect of CAM on male and female students' performance in other chemistry content areas.
2. Similar studies should be conducted using larger samples to examine the effect of CAM on students' retention ability in hybridization and molecular shapes.
3. Future studies should focus on using computerized animations and models on other difficult chemistry concepts such as chemical kinetics, electrochemistry, etc. This would provide more information for greater generalization of conclusions drawn from the findings of the study.

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APPENDICES

APPENDIX A

HYBRIDIZATION PERFORMANCE TEST 1 (HPT-1)

This test has been structured to find out your level of understanding in hybridization and molecular shapes. Write the serial number given to you, do not write your name.

The test is made up of two sections; sections A and B. Section A comprises of multiple-choice questions, kindly select the correct option to each question by circling the letter associated with the correct option. Section B comprise of questions that require that you write your answers in the spaces provided.

Serial Number of Student: ……………….. Male [ ] Female [ ]

SECTION A

1. The shape of sp hybridized orbital is …………..

   A. Linear B. Planar C. Tetrahedral D. Pyramidal

2. The shape of methane (CH_4) is

   A. Linear B. Planar C. Tetrahedral D. Pyramidal

3. Boron trichloride (BCl_3) has a trigonal planar shape and the hybridization state of B is …………

   A. Sp B. Sp^2 C. Sp^3 D. Sp^3d

4. Pi bonds are formed by the

   A. Head-to-head overlap of atomic orbitals

   B. Overlapping of two s-orbitals

   C. Head-on overlapping of two p-orbitals

   D. Side-by-side overlap of two p-orbitals

APPENDIX A CONTINUED

5. The mixing of one s-orbital and two p-orbitals results in the formation of …………..

   A. Two Sp^2 hybrid orbitals
   B. Three Sp^2 hybrid orbitals
   C. Three Sp^3 hybrid orbitals
   D. Four Sp^3 hybrid orbitals

6. How many sigma and pi bonds are present in ethene (C_2H_4)?

   A. 3 sigma, 3 pi
   B. 4 sigma, 2 pi
   C. 5 sigma, 1 pi
   D. 6 sigma, 0 pi

7. Carbon atoms in ethyne (C_2H_2) are both sp hybridized, they are separated at a bond angle of ………………

   A. 107° B. 120° C. 180° D. 109.5°

8. Which of the following molecules has trigonal pyramidal shape?

   A. CH_4 B. CO_2 C. H_2O D. NH_3

9. Which of the following pair of molecules have linear shape?

   A. $BeCl_2$ and CO_2 B. BCl_3 and CO_2 C. C_2H_2 and H_2O D. H_2O and SO_2

10. How many lone-pair(s) is / are present in a molecule of water?

   A. 1 B. 2 C. 3 D. 4

11. Which of the following molecules has tetrahedral shape?

   A. C_2H_2 B. CCl_4 C. CO_2 D. NH_3

12. CH_4, NH_3 and H_2O are all molecules with ……………… electron-group geometry.

A. Linear B. Planar C. Tetrahedral D. Pyramidal

APPENDIX A CONTINUED

13. The shape of a molecule of water is

A. Linear B. Planar C. Tetrahedral D. V-shape

14. A triple bond contains

A. 3 sigma bonds C. 1 sigma, 2 pi bonds

B. 3 pi bonds D. 2 sigma, 1 pi bonds

15. The sharing of two-pairs of electrons results in the formation of ……………..

A. Single covalent bond C. Triple covalent bond

B. Double covalent bond D. Dative covalent bond

16. Sigma bonds are formed by lateral overlap of atomic orbitals. True or False

17. Mixing of one s-orbital with three p-orbitals results in the formation of three sp^3 hybrid orbitals. True or False

18. Water molecule has a V-shape. True or False

19. Both BCl_3 and NH_3 have trigonal planar shape. True or False

20. Both SO_2 and H_2O have the same shape. True or False

SECTION B

21. The central atoms of H_2O and NH_3 are both sp^3 hybridized, however, their bond angles are 104.5° and 107° respectively. Account for the difference in bond angles.

22. Complete the table following table.

Molecule	Hybridization state of central atom	Shape of the molecule
CH_4		
BCl_3		
NH_3		

APPENDIX B

HYBRIDIZATION PERFORMANCE TEST 2 (HPT-2)

This test is structured to find out how far you have understood the lessons taught on hybridization and molecular shapes using computerized animations and models.

Write the serial number given to you, do not write your name.

This test is made up of two sections; sections A and B. Section A comprises of multiple-choice questions, kindly select the correct option to each question by circling the letter associated with it. Section B comprises of questions that require that you write your answers in the spaces provided.

Serial Number of Student: …………… Male [ ] Female [ ]

SECTION A

1. The type of hybridization in NH_3 molecule is …………..

   A. Sp B. Sp^2 C. Sp^3 D. Sp^3d

2. Be in $BeCl_2$ undergoes …………… hybridization.

   A. Sp B. Sp^2 C. Sp^3 D. Sp^3d

3. The sharing of three-pairs of electrons results in the formation of ……………

   A. Single covalent bond C. Triple covalent bond

   B. Double covalent bond D. Dative covalent bond

4. Which of the following molecules has trigonal planar shape?

   A. $BeCl_2$ B. BF_3 C. NH_3 D. PCl_3

5. The linear shape of CO_2 with bond angle of 180° can be attributed to ………………………

   A. Sp B. Sp^2 C. Sp^3 D. Sp^3d

APPENDIX B CONTINUED

6. The angle between any two sp^2 hybrid orbitals in a molecule is ……………

   A. 104° B. 107° C. 120° D. 180°

7. Which of the following overlaps results in the formation of pi bonds?

   A. Overlapping of two s-orbitals
   B. Head-on overlap of two p-orbitals
   C. Head-to-head overlap of atomic orbitals
   D. Side-ways overlap of two p-orbitals

8. Mixing of one s-orbital with three p-orbitals results in the formation of …………...

   A. Two sp^2 hybrid orbitals C. Three sp^3 hybrid orbitals
   B. Three sp^2 hybrid orbitals D. Four sp^3 hybrid orbitals

9. The two carbon atoms in ethyne (C_2H_2) are both ………….. hybridized.

   A. Sp B. Sp^2 C. Sp^3 D. Sp^3d

10. How many lone-pair(s) is / are present in a molecule of ammonia?

    A. 1 B. 2 C. 3 D. 4

11. Which molecule is incorrectly matched with its electronic geometry?

    A. CH_4 – tetrahedral C. NH_3 – trigonal planar
    B. H_2O – tetrahedral D. SO_2 – trigonal planar

APPENDIX B CONTINUED

12. Which molecule is correctly matched with its shape?
    A. CH_4 – square planar   C. NH_3 – trigonal planar
    B. CO_2 – linear   D. SO_2 – linear

13. The number of pi bonds in $H_2C = CH\text{-}CH = CH_2$ is/ are
    A. 1   B. 2   C. 3   D. 4

14. What type of hybrid orbital does carbon exhibits in CX_4 compounds?
    A. Sp   B. Sp^2 C. Sp^3 D. Sp^3d

15. Carbon atoms in ethyne (C_2H_2) are both sp hybridized, they are separated at an angle of
    A. 107°   B. 120°   C. 180°   D. 109.5°

16. Hybridization occurs in the orbitals of different atoms.   True or False

17. Sigma bonds are formed by head-to-head overlap of atomic orbitals.   True or False

18. Both BCl_3 and NH_3 have trigonal planar shape.   True or False

19. A molecule with a linear shape has a bond angle of 120°.   True or False

20. The central atoms in CH_4, NH_3 and H_2O are all sp^3 hybridized.   True or False

SECTION B

21. With the aid of an appropriate diagram, indicate how C=C double bond in ethene is formed.

22. Complete the table below;

Molecule	Hybridization state of central atom	Shape of the molecule
$BeCl_2$		
C_2H_4		
NH_3		

APPENDIX C

PRE-INTERVENTION QUESTIONNAIRE (PIQ-1)

This questionnaire is structured to solicit information about the challenges you face in learning hybridization and molecular shapes. This will enhance the planning of an appropriate intervention that can effectively address your challenges, therefore, answer all questions honestly.

Write the serial number given to you in the space provided, do not write your name.

Answer by ticking [√] in the bracket provided at the end of each item.

Student serial number: …………… Male [ ] Female [ ]

SECTION A

What challenges do you face in learning hybridization of atomic orbitals?

1. I don't understand how orbitals of different energies and shapes mix to give new hybrid orbital. [ ]
2. I don't understand 2sp, 3sp^2, and 4sp^3 hybrid orbitals. [ ]
3. I have a challenge with how two hybrid orbitals overlap to form a bond. [ ]
4. I cannot visualize how orbitals mix to give hybrid orbitals. [ ]
5. I cannot determine the central atom of a heteronuclear molecule. [ ]
6. I don't know how to determine the hybridization state of an atom. [ ]
7. I don't know how to represent hybrid orbital formation by drawing [ ]
8. I cannot describe how sigma and pi bonds are formed. [ ]
9. The concept of hybridization is too abstract [ ]
10. I don't know pi bonds occur in only p-orbitals. [ ]
11. I can't explain formation of single, double and triple bonds from atomic and hybrid orbitals. [ ]

APPENDIX C CONTINUED

SECTION B

What challenges do you face in learning molecular shapes?

12. I don't know the difference between electron-pair geometry and molecular shape. [ ]
13. I don't consider lone-pairs in determining molecular shapes. [ ]
14. I don't know the effects of lone-pairs on molecular shape and bond angle. [ ]
15. I can't predict the correct shapes and bond angle of molecules [ ]
16. I can't sketch the correct shapes of molecules [ ]
17. I can't sketch the different orientations of px, py, and pz orbitals. [ ]
18. To me, all molecules whose central atoms exhibit the same hybridization state have the same shape and bond angle. [ ]

APPENDIX D

POST INTERVENTION QUESTIONNAIRE (PIQ-2)

This questionnaire is structured to solicit information about your view on the integration of computerized animations and models (CAM) in teaching and learning of hybridization and molecular shapes.

Write the serial number given to you in the space provided, do not write your name.

Indicate by ticking [√], the extent to which you agree or disagree with the following statements.

Student serial number: …………… Male [ ] Female [ ]

Item	Statement on CAMs Strategies	Strongly Agree	Agree	Uncertain	Disagree	Strongly Disagree
1	I can visualize the process of hybridization with CAM					
2	CAM helps me to understand concepts better					
3	Learning with CAM is enjoyable					
4	Learning with CAM increases my interest in chemistry					
5	Learning with CAM is boring					
6	CAM helps me understand the effects of lone-pairs on shapes of molecules					
7	I can predict the correct shapes of molecules					
8	I can conceptualize the formation of sigma and pi bonds					
9	CAM helps me to actively participate in teaching and learning process					

10	CAM helps me to perform well in class					
11	I learn from other students in the class when CAM is used.					
12	I can convert 2D structures into 3D structures					
13	CAM makes learning difficult					
14	I wish other topics are taught with CAM					
15	I lack enough skills in the usage of CAM					
16	CAM must be integrated into the teaching and learning of chemistry					
17	My school lacks enough digital resources to support CAM instruction					
18	Instruction with CAM is time consuming					

APPENDIX E

MARKING SCHEME FOR HPT-1

SECTION A

1. A	6. C	11. B	16. False
2. B	7. C	12. C	17. False
3. B	8. D	13. D	18. True
4. D	9. A	14. C	19. False
5. B	10. B	15. B	20. True

SECTION B

21. The central atoms in both NH_3 and H_2O are sp^3 hybridized, however, one of the sp^3 hybrid orbitals of NH_3 is occupied by a lone-pair of electrons which causes a lone-pair bond-pair repulsion and reduce the tetrahedral bond angle from 109.5° to 107°. In H_2O, two of the sp^3 hybrid orbital is occupied with two lone-pairs of electrons. These two lone-pairs repel each other as well as the bonding pairs, which decrease the tetrahedral bond angle highly from 109.5° to 104.5°. The repulsion caused between these lone-pairs with the bonding pairs account for the difference in bond angles.

22.

Molecule	Hybridization state of central atom	Shape of the molecule
CH_4	Sp^3	Tetrahedral
BCl_3	Sp^2	Trigonal planar
NH_3	Sp^3	Trigonal pyramidal

APPENDIX F

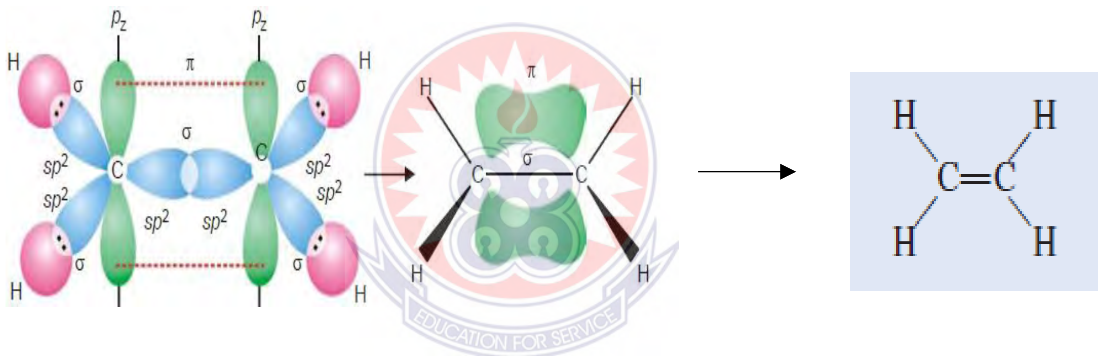
MARKING SCHEME FOR HPT-2

SECTION A

1. C	6. C	11. C	16. False
2. A	7. D	12. B	17. True
3. C	8. D	13. B	18. False
4. B	9. A	14. C	19. False
5. A	10. A	15. C	20. True

SECTION B

21.



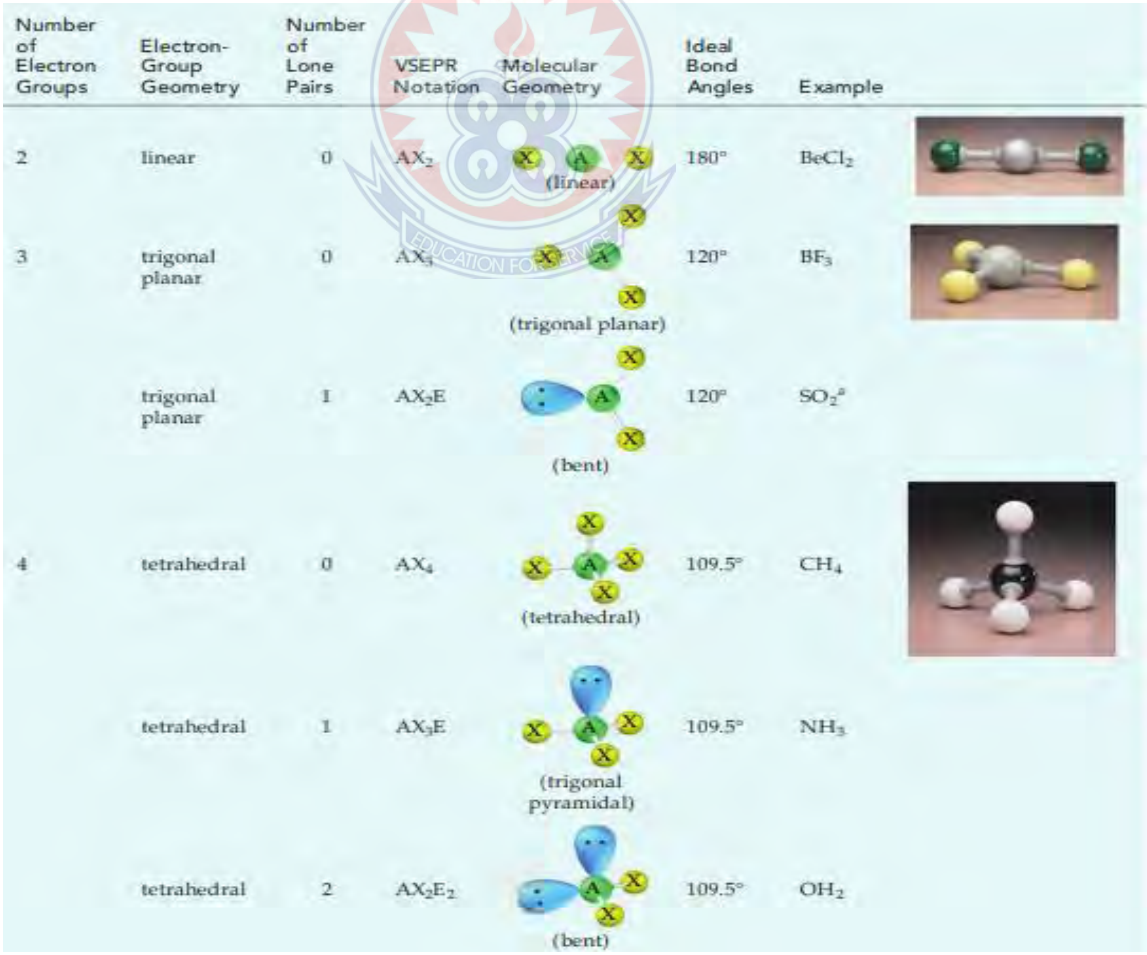
22.

Molecule	Hybridization state of central atom	Shape of the molecule
$BeCl_2$	Sp	Linear
C_2H_4	Sp^2	Trigonal planar
NH_3	Sp^3	Trigonal pyramidal

APPENDIX G

STEPS IN DETERMINING MOLECULAR SHAPE

1. Write Lewis structure of the molecule
2. Two atom molecules always have linear shape. For example; N_2, O_2, H_2, HCl, etc.
3. Molecules with 2 electron-groups with no lone-pair are linear.
4. Molecules with 3 electron-groups with no lone-pair are trigonal planar.
5. Molecules with 3 electron-groups with one lone-pair have bent or V-shape.
6. Molecules with 4 electron-groups with no lone-pair are tetrahedral.
7. Molecules with 4 electron-groups with one lone-pair are trigonal pyramidal.
8. Molecules with 4 electron-groups with two lone-pairs have bent or V-shape.



Number of Electron Groups	Electron-Group Geometry	Number of Lone Pairs	VSEPR Notation	Molecular Geometry	Ideal Bond Angles	Example
2	linear	0	AX_2	(linear)	180°	$BeCl_2$
3	trigonal planar	0	AX_3	(trigonal planar)	120°	BF_3
	trigonal planar	1	AX_2E	(bent)	120°	$SO_2{}^a$
4	tetrahedral	0	AX_4	(tetrahedral)	109.5°	CH_4
	tetrahedral	1	AX_3E	(trigonal pyramidal)	109.5°	NH_3
	tetrahedral	2	AX_2E_2	(bent)	109.5°	OH_2

Source: Adopted from Petrucci, 2007

APPENDIX H

SCHEME OF WORK FOR THE STUDY

WEEK	LESSON	TOPIC/ SUBTOPIC	LESSON OBJECTIVES	TEACHER-LEARNER ACTIVITIES	TEACHING-LEARNING MATERIALS/ REFERENCES
1	1	HYBBRIDIZATION OF ATOMIC ORBITALS. Sub-topic: Concept of hybridization	At the end of the lesson, the students will be able to; (i)draw shapes and orientations of s, and p orbitals. (ii)define hybridization (iii) describe how hybridization occurs in carbon atom.	Teacher revises students' previous knowledge on covalent bond. **Activity 1** (i)Teacher projects the video animation for students to watch and notice the shapes and orientations of s, px, py, and pz orbitals. (ii) Teacher brief and guide students in drawing the shapes and the orientations of s and p orbitals. **Activity 2** (i) Teacher projects video animation showing the process of hybridization in carbon. Teacher guides students to define hybridization. (ii)teacher guides students to describe hybridization in carbon.	Laptop with video animation and model package, projector, mini-speaker, white board. **REF:** Video animation on Hybridization theory.
	2	HYBRIDIZATION OF ATOMIC ORBITALS. Sub-topic:	At the end of the lesson, the students will be able to;	Teacher begins lesson by revising students' RPK on	Laptop with video animation and model

		Formation of sp^3, sp^2, and sp hybrid orbitals.	(i). describe the formation of sp^3 hybrid orbital. (ii). describe the formation of sp^2 hybrid orbital. (iii). describe the formation of sp hybrid orbital.	hybridization, and orientations of s, px, py, and pz orbitals through questioning and answering. **Activity 1** Teacher projects computerized video animations on the formation of sp^3 hybrid orbital. **Activity 2** Teacher projects computerized video animations on the formation of sp^2 hybrid orbital. **Activity 3** Teacher projects computerized video animations on the formation of sp hybrid orbital. **Closure:** Teacher summarizes lesson through oral evaluation.	package, projector, mini-speaker, white board. **REF:** Video animation on Hybridization theory.
2	3	Hybridization of atomic orbitals. Sub-topic: Determination of hybridization state	At the end of the lesson, the students will be able to; (i). determine the number of electron groups around a central atom. (ii) determine the hybridization state of atom using the number of electron groups around	Teacher begins lesson by revising students on writing Lewis structures. **Activity 1** Teacher projects the video animation and guide students on how to determine the electron groups around an atom. **Activity 2** Teacher projects the video	Laptop with video animation and model package, projector, mini-speaker, white board. **REF:** Video animation on Hybridization theory.

			it.	animation and guide students on how to determine the hybridization state of an atom. **Activity 3** Teacher summarizes the video watched, put students in groups and assign them to cooperate and determine the hybridization state of some atoms, present in molecules in the video. **Closure:** Teacher discusses the solutions from the groups, then bring the lesson to close.	
2	4	Hybridization of atomic orbitals. Sub-topic: Formation of sigma and pi bonds.	At the end of the lesson, the students will be able to; (i) define sigma bond and pi bond. (ii) describe the formation of sigma and pi bonds. (iii) show by sketching the formation of sigma and pi bonds in ethene and	Teacher asks students to brainstorm and come out with what they know about single and multiple bonds. **Activity 1** Teacher projects the video animation showing the formation of sigma and pi bonds in ethene and ethyne. Base on the video, teacher guides students to define sigma and pi bonds. Teacher guides students to describe the formation of	Laptop with video animation and model package, projector, mini-speaker, white board. **REF:** Video animation on “Types of hybridization in organic compound”.

			ethyne molecules. (iv). identify the number of sigma and pi bonds in a molecule.	sigma and pi bonds from the video. **Activity 2** Teacher guides students to watch the video carefully, and sketch to show the formation of sigma and pi bonds in ethene and ethyne. **Activity 3** After watching the video, teacher wrote structures of some molecules on the board, and asked students to identify the number of sigma and pi bonds present in each. The molecules are butane, but-2-ene, propanoic acid, pentanol and propene. **Closure:** Teacher leads discussion with the students on the work they did individually, on activity 3.	
3	5	MOLECULAR SHAPES Sub-topic: Determination of molecular shapes.	At the end of the lesson, the students will be able to; (i)define molecular shape. (ii)determine molecular shapes of	Teacher introduces the lesson by revising students on electron group geometry. **Activity 1** Teacher projects video animation on molecular shapes. Base on the video, teacher guides students	Laptop with video animation and model package, projector, mini-speaker, white board. **REF:** Video animation on “Molecular geometry-rules, examples and

			heteronuclear molecules without lone-pairs. (iii)determine molecular shapes of heteronuclear molecules with lone-pairs.	to define molecular shapes. **Activity 2** Teacher guides students to follow the steps outlined in the video for determining molecular shapes. Molecules with linear, trigonal planar, and tetrahedral are discussed. The molecules include $BeCl_2$, BF_3, CH_4, CCl_4. **Activity 3** Teacher guides students to follow the steps outlined in the video for determining molecular shapes for molecules with lone-pairs, identify the effects of lone-pairs on molecule's angle and shape. Molecules with lone-pairs discussed include NH_3, H_2O, SO_2, PCl_3. Activity 4 Teacher facilitates the process for students to determine molecular shapes of molecules available in the video as practice	practice".

				questions. Molecules include BCl_3, N_2, H_2S, PH_3, HCN, CF_4. **Closure:** Teacher summarized the salient points and end lesson.	
3	6	MOLECULAR SHAPES Sub-topic: Construction of molecular shapes with ball-and-stick models.	At the end of the lesson, the students will be able to; (i)construct molecular shapes for some molecules with linear, trigonal, tetrahedral and V-shapes. (ii) convert molecules in 2D representations to 3D representations using ball-and-stick models.	Teacher begins lesson by putting students into smaller groups of 5 members, and supply each group with molecular kits. **Activity 1** Teacher projects the video animation on molecular geometry, and guides groups to construct shapes of molecules displayed in the video. **Activity 2** Teacher guides groups to construct linear, trigonal planar, bent or V-shape, tetrahedral, and trigonal pyramidal shapes of molecules in their 2D forms into 3D shapes using ball-and-stick models. These molecules include CH_4, NH_3, H_2O, SO_2, $CH_3CH_2CH_2CH_3$, C_2H_4, and C_2H_2. **Activity 3** Teacher asked	Molecular kits, Laptop with video animation and model package, projector, mini-speaker, white board. **REF:** Video animation on "Molecular geometry-rules, examples and practice".

				group members to cooperate and construct 3D shapes of molecules they want using the ball-and-stick models. **Closure:** Teacher bases on the groups works and summarizes the lesson.	
4	7	MOLECULAR SHAPES Sub-topic: Sketching of molecular shapes.	At the end of the lesson, the students will be able to; (i)sketch by converting ball-and-stick model shapes into wedge-dash-line structure. (ii) convert molecules in 2D representations to 3D representations using wedge-dash-line structure.	Teacher begins lesson by putting students into smaller groups of 5 members, and supply each group with molecular kits. **Activity 1** Teacher projects the video animation on molecular geometry, and ask groups to construct shapes of molecules displayed in the video, as done during lesson 6. **Activity 2** Teacher guides the groups to sketch the ball-and-stick models they have constructed in their notebooks, using wedge-dash-line structure. The molecules include CH_4, NH_3, H_2O, SO_2, $CH_3CH_2CH_2CH_3$,	Molecular kits, Laptop with video animation and model package, projector, mini-speaker, white board. **REF:** Video animation on "Molecular geometry-rules, examples and practice".

				C_2H_4, and C_2H_2. **Activity 3** Teacher guides students to convert molecules in 2D representations into 3D representations using wedge-dash-line structure. **Closure:** Teacher ends lesson after addressing all challenges on the lesson.	