UNIVERSITY OF EDUCATION, WINNEBA

INVESTIGATING THE EFFECTIVENESS OF COMPUTER SIMULATION ON STUDENTS' PERFORMANCE IN CELL BIOLOGY

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DECLARATION

STUDENT'S DECLARATION

I, Joseph Dominic Andoh-Kesson, declare that this dissertation, with the exception of quotations and references contained in published works which have all been identified and duly acknowledged, is entirely my 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.

…………………………………………………………… (SUPERVISOR)

SIGNATURE: ……………………………………………

DATE: ……………………………………………….

DEDICATION

This work is dedicated to my one and only caring and loving wife Agnes Andoh-Kesson and children Adette Nana Tawiah Andoh-Kesson, Jaden Nanabanyin Andoh-Kesson and Julian Papa Annan Andoh-Kesson whose prayers and sacrifices have brought me this far.

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LIST OF ABBREVIATIONS

ICT: Information and Communication Technology

WASSCE: West African Senior Secondary Certificate Examination

CSIS: Computer Simulation Instructional Strategy

SATiB: Standardised Achievement Test in Biology

GES: Ghana Education Service

ANOVA: Analysis of Variance

HSD: Honest Significant Difference

ABSTRACT

This study examined the effect of computer simulation instructional strategy on the academic performance of Cambridge students in biology. Four research questions guided this study. The action research design was adopted. An intact class of thirty-six grade eight Cambridge Lower Secondary School students were purposively selected as respondents for the study. The computer simulation instructional strategy was used consistently for six weeks to teach biology. After the sixth week, a post-intervention test was administered. The results showed that: The performance of the respondents on the post-intervention test (M=23.32) was significantly better than their performance on the pre-intervention test (M=12.58) indicating that the intervention had a positive impact on students' performance; high ability learners performed nearly the same in the pre-intervention (M=25.44) and post-intervention (M=25.89) tests while medium ability learners performed significantly better in the post-intervention test (M=22.0) than in the pre-intervention test (M=18.78). Also, lower ability learners performed significantly better in the post-intervention test (M=15.45) than in the pre-intervention test (M=12.40) showing that computer simulations impacted low and medium ability learners more than high ability learners; computer simulation instructional strategy proves to be an effective instrument for bolstering the attitude of students towards the learning of biology (post: M=87.55; pre: M=75.36); computer simulation instruction approach had no differential impact on the performance of male and female students taught biology using the method ($p=0.098 >0.05$) . It was recommended that teacher education programmes in Kent International School should develop courses or training sessions that show teachers how to design computer simulations by themselves.

CHAPTER ONE

INTRODUCTION

1.0 Overview

This chapter of the research report presents the background to the study, statement of the problem, purpose and objectives of the study. It also outlined the research questions, significance of the study, delimitations and limitations and organisation of the study.

1.1 Background to the Study

Laboratory work is important to the study of biology. Through conducting laboratory experiments and analysing data, students refine their science process skills as well as having a firm grip of concepts taught by the teacher (Sauter, Uttal, Rapp, Downing, & Jona, 2013). As is well known, the role of the practical side and training in laboratory work performance is imperative to develop understanding of biological facts. Laboratory work is important because it helps students to gradually embody the information through the use of their skills of observation and analysis (Rehn, Moore, Podolefsky & Finkelstein, 2013). Through laboratory work, their abilities to make sound conclusions become better. In addition, laboratory work raises the efficiency of learning and understanding of biological facts (Kiboss, Ndirangu & Wekesa, 2004). Students can develop their knowledge derived from direct interaction with the natural environment.

In Ghana, there is lack of equipment and instruments used to conduct the traditional biology laboratories (Yeboah, 2010). This problem could be addressed through the use of technologies for the development of learning and teaching of biology. New educational technologies are expected to change the way students learn and teachers teach, and the support for the use of computers in education keeps increasing (Kent & McNergney, 2019). The growth in technology integration in education has been spurred from the intent to improve teaching pedagogies and consequently student learning. These techniques contain many educational advantages from which we can create an interactive learning environment that simulates reality.

According to Sauter, Uttal, Rapp, Downing, and Jona (2013), recent technological developments have increased the usage of technologies that supplement interactive computer-based science learning. It is therefore important that science instructors take advantage of the increase in technology based science learning to enhance students understanding. These applications are virtualized laboratories and videos that make it easier for students to understand the processes by making concepts visible as well as interactive. The use of virtualization in experiments enables students to develop abilities and cognitive skills and provides them with accurate scientific observations. According to Shim, Park, Kim, Kim, Park, and Ryu (2003) students play an active role in learning activities through virtual reality that allow them to explore and develop their knowledge through offering the educational resources for teaching biology. Moreover, virtual reality (VR) is one of a set of technologies that depends on more modern devices, which can increase the likelihood of the students' interaction during the learning process. There is a plethora of sources available that provide interactive simulation technology in educational sciences, each of which contains a unique set of features that allow users to interact with the scientific content (Rehn *et al*., 2013). There is therefore the need for teachers to explore the effectiveness of the diverse technologies available for teaching biology through research. That is what has necessitated this research.

1.2 Statement of the Problem

The researcher observed that Kent International School does not have a well-equipped science laboratory for teaching practical activity in biology. This could cause the biology teachers to not expose the students to practical activity and invariably result in the under performance of the students in the subject. Kent and McNergney (2019) asserted that this problem could be addressed through the use of technologies that provide tools to augment or sometimes replace hands-on activity. Nonetheless, Rehn *et al*. (2013) observed that there exists a plethora of resources that provide interactive technology in educational sciences, each of which contains a unique set of features that allow users to interact with the scientific content being taught. It has become necessary, hence, for biology teachers to explore the effectiveness of these technologies for teaching biology through research. The focus of this study, therefore, was to investigate the effectiveness of computer simulation instructional strategy in improving student performance in cell biology.

1.3 Purpose of the Study

The purpose of this study was to investigate the effect of computer simulation instructional strategy on Kent International School science students' performance in biology. The aim was to determine if there were any differences between the learning outcomes of the students before and after computer simulation instructional strategy was used. Furthermore, the study sought to find out whether computer simulation instructional strategy have any differential effect on the performance of male and female students who were taught cell biology.

1.4 Objectives of the Study

The objectives of this research were to:

1. Examine the performance of students on unit test assessments in biology before and after the use of computer simulation instructional strategy to teach cell biology.
2. Assess the effect of computer simulation instructional strategy on the performance of different ability level learners in cell biology using computer simulations.
3. Evaluate the impact of computer simulation instructional strategy on the interest and attitude of students toward cell biology.
4. Determine whether or not computer simulation instructional strategy have any differential effect on the performance of male and female students in cell biology tasks.

1.5 Research Questions

The study was guided by the following research questions:

1. What is the performance of students in biology before and after the use of computer simulation instructional strategy to teach cell biology?
2. Does computer simulation instructional strategy have any effect on the performances of different ability level learners in cell biology using computer simulations?
3. What is the impact of computer simulation instructional strategy on the attitude of students toward cell biology?
4. To what extent does the performance of male students on biology tasks differ from that of female students after using computer simulations to teach cell biology?

1.6 Null Hypothesis

The following null hypotheses were tested at 0.05 level of significance.

1. There is no statistically significant difference between the performance of students before and after using computer simulation instructional strategy to teach cell biology.
2. There is no statistically significant difference between the performance of different ability learners on assessment scores before and after they were taught cell biology using computer simulations.
3. There is no statistically significant difference between the performance of male and female students in cell biology tasks after using computer simulations to teach.

1.7 Operational Definitions

Computer simulation: Computer simulations can be considered a variant of cognitive tools that allow students to test hypothesis and in addition, enable learners to ground cognitive understanding of their action in a situation.

Performance: performance represents the outcomes that indicate the extent to which a person has accomplished specific goals that were the focus of activities in instructional environments, specifically in a test.

Instructional strategy: Instructional strategies are techniques teachers use to help students become independent, strategic learners. These strategies become learning strategies when students independently select the appropriate ones and use them effectively to accomplish tasks or meet goals.

Hands-on activity: This is another term for experiential learning, where individuals learn from partaking in activities rather than passively reading a book or attending a lecture.

Low ability learner: Low ability learners are those who have slower learning pace and higher learning needs. This group of pupils may be less academically capable than their peers.

High ability learner: High ability learners are students whose ability is more advanced than that of similar-aged peers across one or more domains. These domains include intellectual ability, speed of learning and complex thinking patterns.

1.8 Significance of Study

- The students will be the main beneficiaries of this study as they are the point of focus for this study. Simulation will feed students' curiosity and improve their conceptual understanding of biology concepts.
- This study provides useful information on the effectiveness of computer simulation instructional strategy in teaching biology. This could motivate biology teachers to adopt this instructional strategy.
- The findings from this research will augment the pool of data required by educational researchers in their bid to design interventions to solve educational problems in science.
- Finally, findings from this study could form the background to further research work on the topic.

1.9 Limitation of the Study

This study was action research carried out in Kent International School in the Greater Accra Region of Ghana hence the findings cannot be generalised. The outcomes of the study should consequently be applied with circumspection.

1.10 Delimitations of the Study

Only Kent International School students were used for the study. The study was additionally demarcated to an aspect of biology, focusing on cell and cell division in the Cambridge Lower Secondary Science syllabus.

1.11 Organisation of the Study

The study is organised into six (6) chapters. The first chapter outlined the background to the study, the statement of the problem and the research questions. The chapter also presented the significance of the study, the delimitations and limitation encountered in the study. The second chapter presents the review of the related literature. Chapter three discusses the research methodology that was used in the study. The fourth chapter includes the presentation of the data that were collected. In chapter five, the data that have been collected were analysed and discussed. The sixth chapter encompasses the summary of findings, the conclusions that were drawn and the recommendations made thereof.

CHAPTER TWO

LITERATURE REVIEW

2.0 Overview

This chapter discusses the literature relevant to the study. The major objective of the study was to explore the effect of computer simulation instructional strategy on student performance and attitude toward biology. The chapter reviews relevant literature that provides support for the study under the following sectional and sub-sectional headings: conceptual framework of the study, theoretical framework of the study, the use of computer simulations in the teaching and learning process, the use of computer simulation in the teaching of biology, advantages/strengths of computer simulation usage in education, disadvantages/limitation of computer simulation usage in education and empirical review showing the importance of computer simulation integration in education.

2.1 Introduction

Efforts to increase quantitative literacy across the biology curriculum are often hampered by the difficulty of adding more instruction into an already packed schedule and by a paucity of material and human resources. As a result, students graduating from many biology programmes lack sufficient quantitative skills (Gross, 2004; Hoy, 2004).

This systemic problem particularly handicaps biology graduates compared with other

STEM majors and hinders or even thwarts their success in life science careers that require quantitative skills (Gross, 2004; Hoy, 2004). Contemporary biology curricula aim to educate students in three complementary areas: context, concept, and skill literacy (National Research Council, 2003). Traditional biology education focuses primarily on content and concept, while skill literacy is addressed through courses offered by specialized departments (Brent, 2004; Gross, 2004; Hoy, 2004). Such separation of biological context and concept from practical skill literacy instruction transfers the burden of integrating knowledge from those areas squarely upon the

students. Unfortunately, many otherwise excellent students who graduate from biology programmes tend to have an overly contextualized understanding of basic concepts (Masatacusa, Snyder & Hoyt, 2011).

Halpern and Hakel (2003) suggested that decontextualization needs to be actively promoted in biology teaching and recommended abstract representations of scientific concepts as effective decontextualization techniques. The use of simulations and models specifically has been recommended as a technique to enhance the transfer of conceptual knowledge to new contexts (Salomon & Perkins, 2016). Computer hardware and software advances have allowed instructors to model complex biological phenomena. While computer simulations based on mathematical modelling have been developed and used in physics and engineering, and to some degree in chemistry education, their use to enhance biology laboratory courses has been slower to develop (Lemerle, Ventura & Serrano, 2005). Methods for integrating computer simulations have been tried and found to either improve student performance, student attitudes, or both (Hu, Zhou, Sun, Tong & Zhang, 2012), and a review of the relevant literature concludes that the positive learning effects of computer simulations are especially strong in the laboratory setting (Rutten, Van Joolingen & Van der Veen, 2012). Simulation driven by deterministic equations allow students to examine biological phenomena without the encumbrance of noise and experimental errors.

2.2 Theoretical Framework

This study was hinged on the Constructivism Learning Theory [CLT]. Constructivist theory in education is concerned with how knowledge is obtained by learners. Constructivism is in contrast with reductionism and behaviourism, which were the previously dominant theories of learning in the early-mid 20th century (Kelly, 1997), developed by such researchers as Pavlov and Skinner (Schweitzer & Stephenson, 2008). Reductionist and behaviourist theorists saw learning as being a stimulus-response cycle, where the teacher and expert would supply the answers and information. It was the role of the student to respond to the demands of the teacher when asked, and the teacher's role was to set goals, and punish or reward responses through assessment scores or other means (Schweitzer & Stephenson, 2008).

In contrast constructivist theorists believe that behaviourism minimised the role of the student. They argued that students are active participants in the learning process because they create their own knowledge of what is learned through individual interaction with the material (Bachtold, 2013; Huang, 2002). Huang (2002), believed that new knowledge was based on motivation to understand and solve a problem, so educators should work to create learning environments that involve real life situations, creative interaction, and discovery.

There is no single set of constructivist teaching practices that all constructivists use, but reflection, peer-to-peer student centred learning, and hands-on exploration of learning tasks are typical constructivist learning techniques and practices (Schweitzer & Stephenson, 2008). Other researchers emphasize a confrontation with previously held beliefs and modifying these beliefs through interaction with learning materials as being part of the constructivist learning process (Bachtold, 2013). Gordon (2009) summarized the goal of constructivist environments as to "promote experiences that require students to become active, scholarly participators in the learning process" (p. 39). In these environments, teachers are typically seen as facilitators or

guides rather than directors (Huang, 2002).

2.2.1 Constructivism in the science classroom

Much research (Bachtold, 2013; Huang, 2002; Schweitzer & Stephenson, 2008) has been done in the field of constructivism in the science classroom, with two types of constructivism most often being researched: Piaget's Personal Constructivism (PC) and Vygotsky's Social Constructivism (SC) (Bachtold, 2013). Bachtold (2013) highlights three main differences between PC and SC as follows: PC is about individual learning, while SC is based on group learning and PC is focused

on learning through materials and environment while SC is focused on the social group environment. Thirdly, PC pays attention to concepts and knowledge constructed by the individual in order to organize her/his experiential world, whereas SC focuses on language to enable communication among learners.

This study's lessons are based on the Personal Constructivist model of encouraging students to learn concepts through the use of individual learning goals and interaction with material and problem solving. The use of interactive media, though not hands-on in the traditional sense, has the advantage of both stimulating student interest and encouraging them to expand their horizon of knowledge through individual reflection. This reflection is encouraged through the freedom that they have to more deeply explore, as individuals, topics within the lesson of what they find the most interesting, or those that they need to know more about in order to master the material. Finally, the lesson plans in this study were constructivist because the teacher's role was as a guide rather than as the only source of correct information. In order to understand the role of constructivism and interactive technology in teaching biology, it is important to review the discipline of biology and the biology curriculum of Ghana.

2.3 Biology as a Subject

Biology is the science that studies the nature of living creatures. It is a field through which humans can understand all of the living things around them, including plants, animals, microscopic organisms, and so on. Biology is not only about describing living creatures; it is also about how to apply that knowledge in a wide variety of contexts. The knowledge of biology helps develop communities through the preparation of its citizens into fields such as agriculture, medicine, biotechnology and genetic engineering; the benefits of this type of knowledge, and competent people in these fields of study, are an immense benefit for a society (Kiboss, Ndirangu & Wekesa, 2004). Researchers have proposed that there are other benefits for students, as well, in terms of their intellectual development. For example, Page and Reiss (2010) believed that biology has an impact on the development of the physical, emotional and intellectual person from childhood to adulthood, and knowledge of biology helps students to learn about responsible behaviour, and to maintain healthy behaviours. Academically, many areas in a biology class curriculum overlap with other fields of scientific knowledge, particularly physics and chemistry. This overlapping knowledge provides an important opportunity to teach not only biology, but to contribute in the mastery of all scientific subjects in a wider variety of applications and contexts. Despite the aforesaid advantages, many schools and their teachers have found that teaching young people about biology can be challenging, for a number of reasons. In the field of education, researchers have found that teaching sciences can be problematic in terms of the lack of practical instructional tools, or perhaps, even more importantly, a lack of understanding as to how to correctly implement teaching best practices into the biology classroom (Kiboss, Ndirangu & Wekesa, 2004). Ghana has been making changes in the curriculum in order to help teachers better teach their students, but simply introducing curriculum changes may not be enough when it comes to knowing how to teach or use technology in the classroom. To appreciate this, it is imperative for us to explore the teaching methodologies mostly used by Ghanaian biology teachers.

2.3.1 Current research into the teaching of biology in Ghana

In recent years, Ghana has spent much time, money, and effort to improve the materials and curriculum for its students. These changes have come across all subject areas, and include the study of biology. Suliman (2007) described the goal of teaching biology in Ghana as a move from simply memorizing and recalling information, to applying it in different situations and contexts. The new method of teaching biology is different because it takes into account the role of the students as active participants in their learning. The role of the teacher has also changed. The teacher acts as a guide for the students, by helping them take parts of the lesson, such as individual facts and observations, and apply them to broader contexts. This process helps the teacher to connect the concepts that are difficult to understand for students, and contribute to the student' acquisition of abstract concepts that are difficult to learn through traditional teaching methods. This process promotes the learning of science through research and encourages the student to think critically. Through this process, the students can investigate, survey, explore, compare and research topics, all with the goal of both promoting area content knowledge and critical thinking skills. These higher order thinking skills lay the groundwork for students to arrive at their own understandings, through observation and reasoning skill.

In the traditional lecture style of teaching, the answers and ways to understand a concept is through the teacher as the provider of knowledge in the class. The expectations of the students in the curriculum have also changed in terms of how student knowledge is assessed. The focus for assessment and exams used to be on recalling small details and facts. Now, students are expected to be able to explain and understand the way things work, as this creates a more complete, longer-lasting knowledge of the topic.

Experts in the development of new biology curriculum in Ghana have suggested that educators teaching this subject apply a learning quintet cycle (Yeboah, 2010). This cycle consists of five elements, namely: engagement, exploration, explanation, expansion, and evaluation. When a teacher teaches this process, he/she must organize the lesson into five steps. First, engagement is created through the presentation of the problem, which makes the students want to try to solve it. Second, exploration is where the teacher gives students the materials and guidance to collect data. This step is centred on the learner, and the teacher in charge gives students sufficient guidance and suitable materials related the concept to be explored. In the third element, explanation, the teacher directs students' thinking, so that students are asked to provide her/him with the information they have gathered and processed. This helps them to organize their understanding and develop the appropriate language necessary to describe the concept. The expansion is the fourth approach in which the teacher promotes discussion and development of the topic among the students to broaden their understanding and apply what they have learned. The teacher also answers questions from the students. The fifth and final stage is the evaluation stage where the teacher asks questions to students and waits for answers. Also, a student and her colleagues discuss the solutions reached and compare and evaluate their findings with the findings of their classmates. This process of lesson creation can be applied to all subjects, but is especially relevant to the sciences, including biology, as experimentation has the benefit of allowing students to apply what they have learned to hands-on, collaborative tasks.

2.3.2 Laboratory component

Hands-on laboratory experience has been shown to be an extremely beneficial part of learning biology (Aladjana & Aderibigbe, 2007). The laboratory is an essential component of learning and understanding science through the provision of the appropriate environment for action experiences. The laboratory and classroom environment are also necessary for active learning, which can be either physical or abstract (Aladejana & Aderibigbe, 2007). Researchers have proposed that giving students an opportunity to improve their laboratory skills enhances their awareness of ethical issues, health, and safety in sciences (Bonser *et al*. 2013; Flint & Stewart 2010). In addition, the existence of a comfortable and suitable laboratory environment helps to increase the students' curiosity, leading to creativity and success. Aladejana and Aderibigbe (2007) conducted a study in high schools in Nigeria in which 328 students were chosen at random with the goal of trying to improve the quality of the laboratory environment and increase academic performance, as well as positively influence learning outcomes. In this study, students implemented all the activities that were designed by the teacher. Aladejana and Aderibigbe (2007) were able to conclude that the laboratory was an important factor in learning that affected the academic performance of pupils in science. Also, laboratory work promoted the development of student skills such as observation, investigation, accurate reporting, creativity, and risk averse behaviour. The authors explained that in Nigeria there is a lack of necessary equipment and materials for activities inside the laboratory such that it is not enough to do the experiments. According to Aladejana and Aderibigbe (2007) most of the schools suffer from the lack of equipped laboratories where there is a need to improve the environment of the science laboratory. The study suggested a high correlation between the quality of the laboratory environment and the academic performance of students, due to an improvement of science teaching and learning. The authors highlighted the importance of providing equipment and materials for laboratory activities and encouraging students' creativity by giving the student the opportunity to design and conduct experiments, with teachers providing support, suggestions, advice, ideas, feedback, and help to maintain safety standards.

Researchers (Kiboss, Ndirangu & Wekesa, 2004) have pointed to the importance of change in biology lab courses to follow the traditional organizational experiences based on authentic research. The traditional approach to laboratory work has been criticized by some researchers as being like reading a cookbook (Brownell, Kloser, Fukami & Shavelson, 2012). This strategy provides instruction for students step by step, focusing on the ability of students to follow the steps one by one, rather than understanding the process conceptually and developing their own investigative approaches (Brownell *et al*., 2012). Instead of merely following steps, students should be encouraged to develop hands on problem-solving strategies in science, and technology is one safe way to do that (Gabric, Hovance, Comstock, & Harnisch, 2005).

2.4 Teacher-Centred Teaching and Learning in Ghana

According to AI-Faleh (2012), the most commonly implemented teaching method in Ghanaian senior high schools is the traditional lecture method. Al-Faleh (2012) investigated whether there were any significant differences in performance between students who had been exposed to open, discussion-driven classes or the traditional, teacher-lead, classes which focused on lectures in the biology classroom. His study was conducted with first-year students in three senior high schools in Ghana, one in the city of Accra and the two others in the city of Cape Coast. Based on his research, and comparison of test results between the control group (traditional learning method) and the experimental group (discussion-based method), Al-Faleh (2012) was able to draw a number of important conclusions about these strategies of learning. First, there were no significant differences between the applications of any methods in students' educational attainment. Second, although the lecture class offered more structure and control for the teacher, students greatly preferred the discussions, as discussions promoted a sense of autonomy and a way to apply and demonstrate their knowledge in the classroom. The results of a survey to gauge student attitudes towards the two styles of teaching, lecture and discussion, showed that 83% of the students preferred being taught by the discussion method. Al-Faleh (2012) believed that most students preferred the discussion method because of the style of activity and creativity that accompanied this process in the classroom. Finally, Al-Faleh (2012) proposed that despite the fact that students' performance on the assessments in the study was slightly better in the lecture class, this alone does not make the lecture method superior. In fact, Al-Faleh (2012) proposed that the best method would be a combination of the two approaches to learning in the classroom to best meet the needs and preferences of the students and teacher. Using both methods enable the teacher to attract students with different personality types to participate in the classroom. The teacher must use his or her expertise and good judgement to combine both methods in a way that best fits the subject being taught.

2.5 Technology-based Learning

The development of modern technology has broken the traditional educational restrictions and opened new doors of understanding. Technology is a significant factor in improving the educational system through the role of innovation that provides non-traditional tools. These tools help expand the perceptions of students and enhance the learning process. There are some studies that have developed an innovative educational approach through the provision of non-traditional tools in the teaching of biology. Basaran and Gonen (2012) reported that connecting education and students through the internet had a positive effect on academic performance. The authors gave some suggestions for schools to help them achieve education through the internet. For example, computer labs with fast internet access should be provided and students should be allowed to use the computer whenever they need to during their time in school. Gabric, Hovance, Comstock and Harnisch (2005) showed that the effective use of advanced technology and its integration in teaching biology in secondary schools creates an environment that allows students to be scientists in their classrooms. The researchers also conducted interviews with the students in order to understand their perceptions and attitudes towards the use of this technology in the classroom. The results showed that the technology enhances creativity among students and facilitates more productive learning. Also, students are encouraged to use technology-based learning to solve problems, which provides students with information and necessary materials, as well as basic computer skills. There are a few possible problems that accompany the use of technology-based learning in the classroom (Gabric *et al*., 2005). For example, common problems include: a lack of computers for all students; hardware-related problems in older computers, such as being too old to support newer programs; and a lack of expertise on how to use the devices and technology (Gabric *et al*., 2005; Vera, Felez, Cobos, Sanchez-Naranjo & Pinto, 2006). There were some obstacles to implementation faced by teachers in the integration of technology in teaching, which included the lack of knowledge of technology, economic support, and curriculum (Gabric *et al*., 2005). However, if these obstacles are overcome and technological tools are available and students and teachers know how to use them efficiently, technology can offer a lot of support for students in the learning process (Gabric *et al*., 2005). That is to say, the challenges that might arise from the lack of laboratory equipment and apparatus can be overcome by the integration of technology-based learning where all technical and academic needs are met. Accordingly, the role that the use of technology can play in teaching biology is unlimited. In the following section the technological advancements and their role in improving education was discussed. This section addresses some studies which have fostered innovations in biology education, including interactive simulation technology and biology simulation laboratory (Gabric *et al*., 2005).

According to Vera *et al*., (2006), technology-based learning can increase the participation of students in the learning process. Vera *et al*. (2006) stated that there are some obstacles to the development of educational systems using technology such as the lack of knowledge of technology and expertise for teachers. For instance, there are many instructors who are not familiar with the use of technology. Vera *et al*. (2006) found that technology created a spirit of challenge between the researchers to determine an easy way to use technology to make it accessible to all types of users.

2.5.1 The concept of visual aids

Teaching and learning are important elements in education. The teacher uses different approaches to teach their students to engage them in active learning. With the passage of time, altered methods and techniques are discovered in the field of education and the teacher uses different kinds of aids to make learning effective. Most of the problems related to science literacy can be tackled by making science learning interesting. With the help of teaching aids, science learning and teaching could be more interesting and motivating. Visual aids arouse the interest of learners and help the teachers to explain the concepts easily. Visual aids are those instructional aids which are used in the classroom to encourage students learning process. According to Burton (2012), as cited in Shabiralyani and Stephenson, (2015) visual aids are those sensory objects or images which initiate or stimulate and support learning. Chaney and Teel (2013) described visual aids as any devices which can be used to make the learning experience more real, more accurate and more active. It has been proven that an activity that motivate children also leads to successful learning and that motivation is strongly link to the child's involvement in the learning process (Rieber, 2010). Visual aid which arouses interest of students also motivates students and link to the students' involvement in the learning process. The findings of many researchers support the use of visual aids, for instance, Rieber's (2010) research support the use of animated graphics. Also, a lot of findings by several researchers support the use of animations and pictures which are also visual aids. For instance, Kieras (2012) investigated the effects of animated and static graphics on students' ability to understand the operation of an energy system. Students studied conceptual information about the system in the form of text or in the form of static or animated diagrams. Students who learned from the animated graphic performed significantly better than those who learned from a static graphic who also performed better than those who learned from text. Gautam (2019) utilised computer animations as an effective tool for teaching science. Form his study, he concluded that computer animation offered a strong medium for teaching and learning of science. The visual image of an abstract phenomenon on the monitor gives a clear understanding of the different scientific concepts to the students. In the use of computer assisted instruction (CAI), the students grasp the knowledge and understand it better and applied different scientific phenomena clearly and correctly. In the normal classroom situation (without computer), the concepts are not often clearly explained but the computer can make the concepts clearer and enhance the understanding of the students (Rieber, 2010).

2.5.2 Interactive simulation technology

Adams *et al.* (2008) revealed that interactive simulation technology had received the attention of educators as a new addition to the classroom. The researchers determined that research into the ability of simulation to improve student understanding and studies investigating how to effectively design programmes and efficiently use the technology was very limited. Computer simulations are “techniques which aim to provide the student with a highly simplified reproduction of part of a real or imaginary world.” They are considered “one of the most effective ways to promote deep conceptual understanding of the real world" (O’Haver, 2000). Computer simulations are computer-generated versions of real world objects or processes (Strangman & Hall, 2003). It therefore allow learners to relate the concept being studied to the real world.

According to Lunce (2006), educational simulations are generally classified into four types:

- Physical
- Iterative
- Procedural
- Situational

In a physical simulation, a learner manipulates variables in an open-ended environment and observes the results. For instance, in a global weather patterns simulation, the student can manipulate certain parameters and observe the result.

In iterative simulations, the student conducts scientific research, tests hypotheses, and observes the outcomes in a discovery learning environment. This type of simulation teaches phenomena which cannot be easily observed in real situations, such as phenomena from biology.

In procedural simulations, the student interacts with simulated objects to learn skills required for real world practice. For example, the student manipulates simulated laboratory equipment to prepare for working in a real-world laboratory setting.

In situational simulations, human behaviour is simulated with focus on people's attitudes. Role-playing is often used in these simulations.

Computer simulation, representing a new trend in computer technology, has been applied in many fields including military, medical schools, and educational institutions. Some studies have been conducted to compare the effectiveness of computer simulation with that of other forms of instructional approaches. The effectiveness of using computer simulation has been compared with that of traditional labs (Bourque & Carlson, 2017; Choi & Gennaro, 2017; Gaddis, 2001), computer simulation in addition to hands-on practice (Akpan & Andrew, 2000). In addition, instructional sequences such as using computer simulation both before and after traditional labs have also been compared (Alkazemi, 2003). With the rapid development of computer technology, some virtual labs have also been set up. At the same time, some studies have also been conducted to compare the effectiveness of virtual labs with physical labs (Sicker, Lookabaugh, Santos & Barnes, 2005). The research results show that computer simulations sometimes can replace real labs. For example, the software developed by the Multiverse Project (Institute for Computer Based Learning, 1999) provides detailed explanations of lab assignments and the anticipated results of experiments.

Another study, conducted by Kruper and Nelson (2011), on computer simulation Biota simulates a biology laboratory experiment. Biota simulates processes influencing sizes of plant and animal populations. They compared students in the traditional wet lab with the simulated lab on the development of science reasoning skills and differences in the learning environments.

They found that students the Biota lab group could perform experiments several times while the wet lab group could only perform one experiment. The treatment and control groups did not differ significantly in terms of science reasoning skills.

Computer simulation allows students to observe and interact with a real-world. Computer-simulated experiment may be a good substitute for a laboratory experience in the teaching of some concepts (Winn, Stahr, Sarason, Fruland, Oppenheimer & Lee, 2005). According to Mintz (2013), one of the most promising computer applications in science instruction is the use of simulations for teaching material, which cannot be taught by traditional labs. For example, Choi and Gennaro (2017) compared the effectiveness of computer simulation with hands-on practice for teaching junior high school students the concept of volume displacement. They found that there were no significant differences between the two instructional methods.

Computer simulations can be used in distance education (Lara & Alfonseca, 2001). Many educators encounter the challenge to deliver the hands-on lab portion in distance-learning courses. Computer simulations may be an alternative for hands-on practice in distance learning. In addition to providing distance access, they offer pedagogic benefits for science laboratories. According to Hofstein and Lunetta (2003), interacting with instructional simulations can help students understand a real system, process or phenomenon. The researcher also believes that, such interaction with educational simulations goes a long way to arouse learners interest in the subject area being taught. Computer simulations are good tools for individual learning. Distance labs not only let instructors and students have synchronizing access to lab content, but also provide constant access whenever needed by students (Forinash & Wisman, 2001).

Computer simulations have many advantages over other instructional approaches and media. A term closely related to computer simulation is fidelity. Fidelity refers to the accuracy with which the simulation models a real-world system or phenomena (Alessi & Trollip, 2001). A well-designed computer simulation can have a high degree of fidelity and facilitate learning by simplifying or omitting elements present in a real-world setting. Simulation may be superior to other learning media (such as textbooks, lectures, and tutorial courseware). This is because simulation simulates real-world experiences and may increase students' intrinsic motivation by engaging them in solving challenging problems (Akpan, 2002; Winn *et al.*, 2005). In comparison to other instructional approaches, computer simulation offers learners opportunities to learn in a relatively authentic context, to perform task without stress, to systematically explore both realistic and hypothetical situations, to change the time scale of events, and to interact with simplified versions of the process or system being simulated (Alessi & Trollip, 2001). Computer simulation provides students with opportunities to observe certain processes that happen too quickly or too slowly in real life (Akpan, 2002). Computer simulations can lead to learning transfer, which means that learned knowledge is successfully applied in real-world environments (Khoo & Koh, 2018). In addition, computer simulations are probably more efficient instructional tools for learning in some content areas. Simulations provide students with environments that could be dangerous, expensive, or even impossible to observe in the real-world situations.

Computer simulations also have disadvantages in comparison with other instructional methods. Computer simulation may be more time-consuming than other instructional strategies since many computer simulations concentrate on problem solving. Without proper coaching, scaffolding, feedback, and debriefing, the student learns little from the discovery learning through simulations (Lunce, 2006). Some argue that educational simulations oversimplify the complexities of real-life situations, giving the learner an inaccurate understanding of a real-life problem (Heinich, Molenda, Russell, & Smaldino, 2019). In addition, development of educational simulations may need a big investment of time, effort, and money (Lunce, 2006).

Most early research on computer simulations was on the effectiveness of computer simulations on students' learning (Akpan, 2002). Despite this, the literature on computer-based instructional simulations is filled with contradictions concerning their use and effectiveness (Thomas & Hooper, 2011). The literature has also revealed that computer simulation can help alleviate misconception, enhance learning transfer, improve such skills as problem-solving and high-order thinking skills, and develop content knowledge (Strangman & Hall, 2003).

2.6 Impact of Computer Simulations on Acquiring Factual, Conceptual and Procedural Knowledge in Science

It is common knowledge that technology plays an important role in learning 21st century science. Allowing students to use technology in their learning would give them a glimpse on how scientists are currently working, as they frequently use a number of technological tools in their daily practice (Bran, Gray, Piety & Silver-Pacuilla, 2010). Computer simulations provide students with an open learning environment, which gives them an opportunity to:

- develop an understanding of physical phenomena and laws by developing hypotheses and testing ideas
- develop an understanding of the relations between physical concepts, variables and phenomena by isolating and manipulating parameters
- utilise a variety of representations, including pictures, animations, graphs, vectors and numerical data displays, which help them understand the underlying concepts, relationships and processes
- demonstrate their portrayal and mental models of the physical world
- employ an investigative approach to phenomena that are difficult to experience in a classroom or lab environments, due to their complexity, technical difficulty, money or time consumption, or because they occur too fast to be understood by just observing them in real- life settings (Jimoyiannis & Komis, 2001).

Adams, Reid, Lemaster, McKagan, Perkins and Wieman (2008) studied the integration of computer simulations into the teaching of “Sound Waves.” Adams *et al*. (2008) found that one of the significances of using computer simulations was that not only do they attract students’ attention but they also afford the student an opportunity to see animated motions while interacting with the simulation. As a result, new ideas would form and students would begin to make connections between the information provided by the simulation and their previous knowledge. The study of Adams *et al*. (2008) also resulted in more findings, which were illustrated when students encountered a word in the simulation that they did not know. When that happened, they attempted to play with the control that was labelled with the unknown word and subsequently created a working definition for the word. For example, “Frequency” and “Amplitude” were words students were unable to clearly describe before exploring the “Sound Waves” simulation. After playing around with the simulation, students correctly explained the meaning of these words by using visuals from the simulation. A few weeks later, the same students were interviewed about “Radio Waves”, and they used the visual descriptions from “Sound Waves’ to describe frequency and amplitude. Later on, these same students used “Radio Waves” to create an accurate working definition of an “Electric Field” (Adams *et al*., 2008)

In a study conducted on science students learning about electric circuits, Finkelstein, Adams, Keller, Kohl, Perkins, Podolefsky, Reid and LeMaster (2005) discovered a surprising result about computer simulations. In their study, Finkelstein *et al*. (2005) provided a group of students with real lab equipment, while they furnished another group of students with computer simulations that modelled electron flow. Both groups were enquired to fill a conceptual survey and to perform thought-provoking tasks involving assembling real circuits and describing how they worked. The researchers found that the group of students who interacted with computer simulations performed better than their counterparts in both abstract and hands-on tasks. Finkelstein *et al*. (2005) concluded that computer simulations could enhance students' manipulative skills and mastery of physics concepts better than traditional laboratory experiments.

Podolefsky, Perkins and Adams (2010) studied how students use of computer simulations to explore topics in biology, predominantly, "Cells and their Division." In their research, Podolefsky *et al*. (2010) focused on detecting one type of inquiry, the "engaged exploration". It can be explained as a process during which students actively interact with educational materials, explore through their own questioning, and are engaged in sense making. after observing and interviewing students, Podolefsky *et al*. (2010) noticed that with minimal explicit guidance, students were able to use the simulation to explore how animal cells divide and answered questions on the concept. Even though the simulations were lithe enough to afford students a chance to choose their own learning path, they also had some constraints, which were beneficial in making students' choices generally productive. The simulations also brought the advantage of connecting students to the concrete world, by providing them with representations that were not available in the real world and by creating analogies to help learners understand and create connections across multiple cognitive domains.

Furthermore, the simulations also encouraged a high level of interactivity with dynamic and immediate feedback to the students. Those features enabled students to ask questions and answer them in ways that is usually not supported in traditional educational settings (Podolefsky *et al*., 2010).

McKagan, Perkins, Dubson, Malley, Reid, LeMaster and Wieman (2008) researched about integration of computer simulation in learning biology. They (McKagan *et al*., 2008) found that the simulations' high interactivity, which enabled students to adjust controls and observe immediate animated response, has helped students engage with the content and establish cause-and-effect relationships. This interaction also appeared to be particularly effective for helping students construct understanding and intuition for abstract and unfamiliar biology phenomena. According to McKagan *et al*. (2008), this has the potential to radically transform the way biology is taught because it allows the instructor to focus on the problems that are most important for students to understand rather than on the concepts that are easiest to comprehend.

Additional pieces of research were also performed to test the efficiency of computer simulations on the performance students in science subjects (McKagan *et al*., 2008). findings from these studies confirmed that with the implementation of simulations in the science curriculum, including both interactive lectures and homework using computer simulation, learning was much effective than with traditional instruction.

Tambade and Wagh (2011) researched into the efficiency of computer simulations in easing biology concepts, precisely excretion, for year-three undergraduate students. Their research focused on testing how much computer simulations could aid learners describe the processes involved in excretion of waste from the human body, as well as maintain conceptual comprehension in that area of biology. Participants were grouped into a control group, who received traditional instruction through lecturing, and an experimental group, who was taught using cooperative learning approach, with integration of interactive computer simulations package. The most beneficial features of this package were supporting student-student and student-teacher interactions, in providing information about every aspect of the phenomena related to the subject, and in presenting concepts in different ways.

The outcomes of the study showed that the interactive computer simulation instruction was efficient in promoting conceptual understanding of excretion, as the experimental group, who experienced such tutoring, had an average normalised increase 3.64 times more than that of the control group. Also, further analysis showed that students of the experimental group better understood the processes of excretion in biology than their peers from the control group. Tambade and Wagh (2011) concluded that computer simulations could help students diminish their misconceptions in excretion and develop a functional understanding of biology concepts.

2.7 Impact of Computer Simulations on the Performance of Students with Different Abilities

Research revealed that computer simulations have differential impact on students' academic performance, depending on their academic levels or capabilities (Tambade and Wagh, 2011). Yildiz and Atkins (2016) studied the impact of multiple computer simulations on the learning of students with different abilities. The biology topic that was taught in this study was "Skeletal System". The investigation of students' performance revealed mixed results. Yildiz and Atkins (2016) found that the same simulation could have varied effects on students with different sexes and previous performance levels. For instance, moderate achieving students took advantage of the possibility to repeat the same experiment many times to build confidence in their understanding. However, high achieving male students scored less in the post-test compared to the pre-test. This was attributed to the fact that the lack of challenge in using computer simulations might have caused boredom and loss of concentration for these students. At the end of their study, Yildiz and Atkins (2016) recommended that computer simulations should be carefully differentiated for students of different abilities.

A study was performed in Nigeria to investigate the impact of computer simulations on students' success in practical biology, based on their prior academic ability. The study comprised three treatment groups. The first group used computer- simulated experiments only, the second group used hands-on activity only, and the third group used both computer simulations and hands-on activity. Students' performance was an amalgamation of their scores on Manipulative Skills in Biology Practical (MSBP) and Biology Achievement Test (BAT). Outcomes revealed that students who used both computer simulations and hands-on activity performed best among the three categories while students who were exposed to hands-on activity only had the lowest scores in MSBP and BAT (Adegoke & Chukwunenye, 2013).

Chang, Chen, Lin and Sung (2008) conducted a study in Taipei to examine the impact of learning support on simulation-based learning in three learning models: experiment prompting, a hypothesis menu, and step guidance. The study focused on the topic of digestion in mammals, and adopted two experiments. The first experiment included one-hundred and fifty-three senior high school students, who were grouped into a

control group (N = 39), experimental group one (N = 39), experimental group two (N = 40), and experimental group three (N = 35). Findings from this experiment established that students who used computer simulations in their studies recorded a significant advantage over students who used laboratory-based learning. Chang *et al*. (2008) inferred that any type of simulation-based learning that provides learning support is more efficient than laboratory learning. The second experimental group included two-hundred and thirty-one senior high school students who were grouped into experimental group one (N = 78), experimental group two (N = 79), and a control group (N = 74). Findings from this experiment echoed a substantial efficiency of computer simulations in learning biology. However, the inconsequential interaction between learning models and abstract reasoning abilities showed that different learning models do not have different effects on individuals with different abstract reasoning abilities. Furthermore, it was noted that students with higher abstract reasoning abilities had higher gains from simulation-based learning than students of lower abstract reasoning, and that students who were subjected to computer simulations had higher results than those who received hands-on laboratory activity (Chang *et al*., 2008).

2.8 Strengths of Computer Simulation Usage in Education

Computer simulation is useful in education owing to its interactivity, litheness, and its ability to incorporate different media that supports learning, take into account individual differences among learners and maximise students' motivation. The delivery of interaction between the learner and the learning material is the utmost benefit of computer simulations in comparison with other instructional approaches. Interactivity allows control over the presented content to a certain degree: learners can change parameters, observe their results or respond to choose options. Learners can also control the pace of learning and the number of repetitions to meet their individual needs.

Additionally, the capability of computer simulations to offer feedback, custom-made for the needs of learners discriminates computer simulations from other pedagogical approaches.

Nevertheless, the use of computer simulations by learners has to be supported by very skilled instructors who must guide students through the learning process and provide them with appropriate and effective learning strategies.

Computer simulation offers a variety of media, combined in a meaningful manner that affords learners an opportunity to experience very interactive lessons that includes animations and simulations.

Often, presentations supported by attractive images or animations are visually

more appealing than static texts, and they can support or complement the information presented. Computer animations could also appeal to many types of learning preferences; some learners profit more from learning by reading, some by hearing and some by watching, etc., computer simulations deliver these varied modes in one presentation. In addition, the use of computer simulation allows for different ways of working. Students can decide how to explore the materials as well as how to use interactive and collaborative tools.

Additionally, students can adjust their learning processes according to their abilities and preferences. They can work according to their interests, repeat material as much as they want. The use of computer simulation can thus be custom-made to serve students' differences in interests, social and cultural backgrounds, learning preferences and pace, etc.

Individual learning can promote active, self-directed learning. More so, computer simulation could be used to facilitate group work. Small groups of students can work through multimedia applications together to learn from each other as well as to improve their dialogue skills.

The interactive opportunities presented by computer simulations lead to high flexibility, which can be very helpful for students with special needs. For instance, Dyslexic students can use artificial speech to become familiar with the content of digital texts. Andresen and van den Brink (2013) found that children suffering from autism show an increase of phonologic awareness and word reading by using computer simulations. Learners with varied degrees of physical impairments could benefit from learning with computer simulations, because the computer is flexible enough to meet individual needs; they can repeat as many times as they want, can hear it loud, etc. (Andresen & van den Brink, 2013). For deaf students, the visual presentation of content improves their motivation to learn (Andresen & van den Brink, 2013).

2.9 Limitations of Computer Simulation Usage in Education

Most learners are unable to manage the freedom provided by computer simulations. Despite their usefulness in education, usage of computer simulation to facilitate lessons often comes with some challenges.

Difficult to construct: Creating audio, video and graphical materials and integrating them into simulations can be more challenging than creating ordinary texts. This process can be tedious and time consuming.

Social exclusion: Not all members of a society can be involved in the use of technology due to lack of access to the Internet or lack of hardware to make full use of the educational material on the web.

Equipment problems: Hardware and software needs to be configured in a way that their usage is as simple and as straight forwarded as possible. Lack of these equipment could hinder the usage of this technology in education.

Bandwidth issue: Limited bandwidth means slow performance for sound, graphics and video, interrupting streaming and causing long waits for download that can affect the ease of learning.

Computer screens aren't paper: The content on screens may not be as easy to read as the content on paper. If there are large chunks of information that need to be read from top to bottom, it is probably best to view such a document on paper. Books and journal articles may still be better to read on paper. End users often prefer to use technology to search for information, but when it comes to reading, they tend to read from print-outs.

2.10 Other Instructional Approaches

There are different pedagogical approaches to teaching biology. Each type has its pros and cons. Instructional approach, according to Ndirangu (2007) is the technique used to impart knowledge to students; it is the means by which the teacher attempts to impart the desired experience. To Kimweri (2004), instructional approach refers to the variety of ways in which a learning task is managed to facilitate the learning process.

Instructional approach was also defined by Osokoye (2004) as the strategy or plan that outline the strategy that teachers intend to use to achieve the desirable objectives;

this involves the way teachers organize and use teaching tools and material to meet teaching objectives.

The choice of a preferable instructional approach by the instructor is dependent on several factors (Ndirangu, 2007). Among these factors may be the content to be taught, the objectives which the teacher plans to achieve, the availability of teaching and learning resources and the ability and willingness of the teacher to improvise if conventional teaching aids are not available. Evaluation and follow-up activities as well as individual learner differences are also factors to consider. Several pieces of research have been conducted to investigate the effectiveness of different instructional approaches. For instance, Asikhia (2010), found that qualification of teachers and students' environment do not influence students' performance but rather, teachers' approach to teaching influence academic performance. Findings of this research are supported by the study conducted in the USA by Haas (2002) about the impact of instructional approach on students' performance. This study examined various instructional approaches used in science subjects at A-level. The study found that instructional approach influenced students' learning to a great extent. Another study on instructional approach was carried out by Gulobia, Wokadala and Bategeka (2010) in Uganda. This study analysed the link between educational inputs; instructional approach and pupils' performance among grade 5 students. The findings showed that teaching and learning strategies contribute to better school performance.

Although several studies (Gulobia *et al*., 2010; Haas, 2002; Asikhia, 2010) supported the idea that instructional approaches influenced students' academic performance, it is highly likely that some instructional approaches can better enhance learners' academic performance than others. Gulobia *et al*. (2010) argued that instructional approaches espoused to teach biology lessons could be broadly categorised in to two;

teacher-centred, which are viewed to be somewhat ineffective in the impartation of knowledge and student-centred, which are viewed as more effective in the impartation of knowledge. Below is a discussion of the two major groups and some teaching methods that can be classified under them.

2.11 Learner Centred Instructional Approaches

This method of teaching is student oriented. Here, the learner is vigorously engaged in the process of teaching and learning. They are allowed to do, manipulate, ask and experience. Bruner (1960) asserted that students need a rich supply of meaningful examples and manipulatives to help make ideas and relationships come to life. Some instructional approaches that are categorised under this group are discussed below.

2.11.1 Question and answer (citation)

Question and answer is defined as a method both for teaching and oral testing based on the type and use of questions. Questioning techniques are one of the basic and successful ways of stimulating students thinking and learning (Ndirangu, 2007). It is applicable to all teaching approaches and methods.

2.11.2 Discussion

Discussion approach to instruction is an important component of any teaching or learning situation which allows students to share their ideas (Ndirangu, 2007). It can be used at the beginning of a topic to ascertain students' preconceived notion of the subject matter. Or toward the end of a subtopic by presenting the student with a new situation and asking them to explain it in terms of what they have just learned. Discussion method is a teaching and learning strategy that entails sharing and exchange of ideas, experience and opinion (Kimweri, 2004). Strengths of discussion method are; increases the depth of learners' understanding, enhances motivation and generates greater involvement of the learners, promotes leadership role skills, develops skills of organizing and presenting ideas to others in a logical form and develops a spirit of cooperation among learners. In spite of the strengths, there are also limitations of discussion method which includes; time-consuming, can be used effectively with a limited number of learners, if not well handled some extrovert learners may dominate the discussion.

2.11.3 Brainstorming

Brainstorming is a teaching technique in which every pupil's response that applies to a given topic is acceptable (MIE, 2004). The strengths of brainstorming are; promotes exploration, analysis and problem-solving skills, develop the sense of cooperation and group cohesiveness in problem-solving, encourages the generation of creative ideas, promotes the generation of initiatives in searching solutions to problems. The limitations of brainstorming are; it is time-consuming if not planned, more useful to a limited number of learners and need thorough preparation.

2.11.4 Peer instruction

Peer Instruction (PI) is a research-based pedagogy for teaching large introductory science courses (Fagen & Mazur, 2003). It is a method created to help make lectures more interactive and to get students intellectually engaged with what is going on. PI provides a structured environment for students to voice their idea and resolve individual misunderstandings by talking with their peer (Gok, 2012). Peer instruction is a cooperative learning technique that promotes critical thinking, problem-solving, and decision-making skills (Rao & Dicarlo, 2000). This method has the advantage of engaging the student and making the lesson more interesting to the student. It also has the tremendous importance of giving the teacher significant feedback about where the class is and what it knows.

Despite these arrays of teaching methods being advocated in literature, there is no one universally accepted method. Both learners centred and teacher centred methods of teaching are important in teaching and learning (Haas, 2002; Gulobia *et al*., 2010), and each is appropriate depending on the environment within which they are used. For teaching to be more effectively done, a combination of these methods should be employed since education has many different types of approach and context.

2.12 Teacher-Centred Instructional Approach

Teacher-centred approaches to instruction, also referred to as the traditional method of teaching usually involves instructor-centred instruction, dominated by "chalk and talk" teaching, lecturing, note copying by learners, factual knowledge, abstract concepts, and demonstrations (Onwu & Stoffels, 2005). In a typical teacher centred science class, the educator provides a few examples or solves a few problems on the board. In some cases, the teacher performs experimental demonstrations. Learners in such classes listen to the educator and write notes, but hardly ever ask questions or make remarks (Briscoe & Prayaga, 2004; Kang & Wallace, 2005). This mode of handling science courses may cause students not to appreciate the nature of science. For example, a report by the Organization for Economic Cooperation and Development (OECD) states that most learners at high-school level are of the view that science teaching lacks a sense of community, does not reflect their experience of the world or contemporary research, involves too much repetition, does not provide a good overview of the subject, and offers little room for discussion. Other researchers

(McCarthy & Anderson, 2010) have indicated that the traditional ways of teaching science usually involve little active learning, and frequently cause learners to become disengaged and unmotivated.

The subsequent sections examine the literature on some of the traditional teaching approaches used in the teaching of biology.

2.12.1 Lecture

The lecture method is a one-way communication where teacher talks to students in an autocratic way and the student have no opportunity to ask questions or offer comments during the lesson (MIE, 2004). The lecture method is useful when introducing new subject matter or presenting overview summaries to students. It is also useful when teaching groups of any size and assists the teacher to cover a lot of content in a short space of time. Despite the strengths of lecture method, it has limitations. It does not take into account; individual needs, feeling or interest of students. No feedback from students is required, if not properly planned can lead to boredom, the quality of learning through lecture is poor and not permanent. Finally, the teacher spends a lot of time preparing detailed notes which are rarely learned by the student.

2.12.2 Presentation

Presentation method of teaching involves motivating listeners to accept a new idea, alter an existing opinion or act on a given premise. The strengths of the method include mastery of the topic by the students, increases confidence among students, is a good way to learn, student search a lot of books to collect material. Nonetheless, presentation method has the following disadvantages; learners may collect erroneous data, students with low confidence level may find it difficult to engage themselves in the activity, it is time-consuming as the presenter spends a lot of time gathering relevant information.

2.12.3 Seminar

Seminar method is structured group discussion that may follow after a formal lecture or some sort of experience (Kimweri, 2004). The strengths of the seminar method are to stimulate and test learners' ability of comprehension, promote learners' ability of understanding and questioning, develop learner's sense of self – reliance, cooperation and responsibility, ability in report writing and presentation to fellow learners for the exchange of view and decision making. The limitations of seminar method are; need enough time for the leaner or presenter to plan, some learners especially those who are shy and reserved may not be able to participate effectively during discussion time and some learners, particularly the vocal ones might dominate the discussion.

2.12.4 Demonstration

The demonstration method is a practical display or exhibition of a process to show or point out clearly the fundamental principles or actions involved (Kimweri, 2004). Teaching by demonstration is a useful tool available to the teacher and plays an important part in the teaching of skills; however, for a demonstration to be effective, it should immediately be followed by a practical session in order to reinforce procedures (Kimweri, 2004). The strengths of demonstration include; learners get the actual experience of what they are learning, interesting to learners and thus promote their attention and retention. The limitations of the demonstration method are; time-consuming and expensive, needs thorough preparation, practice and rehearsal before the session, enough teaching and learning materials are required to successfully conduct a demonstration, it is more appealing when used with a group that has a limited number of learners. Other methods of teaching are role play method, case study, and field trips.

2.13 Factors that Influence the Choice of Instructional Approach

The choice of a method of teaching may be dependent on different factors. For example, knowledge of the teacher and flexibility of the learner (MIE, 2004). in order to make an informed choice of teaching method(s) in the teaching and learning process the teacher must know; the teaching methods available, the strengths and weaknesses of each method, the purpose that each can serve and how each method can be used in practice. Other considerations in choosing a method of teaching are the number of students to be taught, age, time and prior knowledge of the learner.

2.14 Conceptual Framework

The educational model underpinning this research is the Information Processing Model [IPM]. Information processing model focuses on how people attend to environmental events, encode information to be learned and relate it to knowledge in memory, store new knowledge in memory, and retrieve it as needed (Shuell, 1986). The tenets of this model are as follows:

- Humans are processors of information.
- The mind is an information-processing system.
- Cognition is a series of mental processes.
- Learning is the acquisition of mental representations.

2.14.1 Assumptions of IPM

Information processing theorists challenged the idea inherent in behaviourism that learning involves forming associations between stimuli and responses. Information processing theorists do not reject associations, because they postulate that forming associations between bits of knowledge helps to facilitate their acquisition and storage in memory. Rather, these theorists are less concerned with external conditions and focus more on internal (mental) processes that intervene between stimuli and responses. Learners are active seekers and processors of information. Unlike behaviourists who said that people respond when stimuli impinge on them, information processing theorists contend that people select and attend to features of the environment, transform and rehearse information, relate new information to previously acquired knowledge, and organize knowledge to make it meaningful (Mayer, 1996).

Information processing theories differ in their views on which cognitive processes are important and how they operate, but they share some common assumptions (Schunk, 2012). One is that information processing occurs in stages that intervene between receiving a stimulus and producing a response. A corollary is that the form of information, or how it is represented mentally, differs depending on the stage. The stages are qualitatively different from one another. Another assumption is that information processing is analogous to computer processing, at least metaphorically. The human system functions similar to a computer: It receives information, stores it in memory, and retrieves it as necessary. Cognitive processing is remarkably efficient; there is little waste or overlap. Researchers differ in how far they extend this analogy. For some, the computer analogy is nothing more than a metaphor. Others employ computers to simulate activities of humans. The field of artificial intelligence is concerned with programming computers to engage in human activities such as thinking, using language, and solving problems (Schunk, 2012). Researchers also assume that information processing is involved in all cognitive activities: perceiving, rehearsing, thinking, problem solving, remembering, forgetting, and imaging (Farnham-Diggory, 1992; Matlin, 2009; Mayer, 1996; Shuell, 1986; Terry, 2009). Information processing extends beyond human learning as traditionally delineated.

2.14.2 Tenets of IPM

Figure 1 shows an information processing model that incorporates processing stages. Information processing begins when a stimulus input (e.g., visual, auditory) impinges on one or more senses (e.g., hearing, sight, touch). The appropriate sensory register receives the input and holds it briefly in sensory form. It is here that perception (pattern recognition) occurs, which is the process of assigning meaning to a stimulus input. This typically does not involve naming because naming takes time and information stays in the sensory register for only a fraction of a second. Rather, perception involves matching an input to known information.

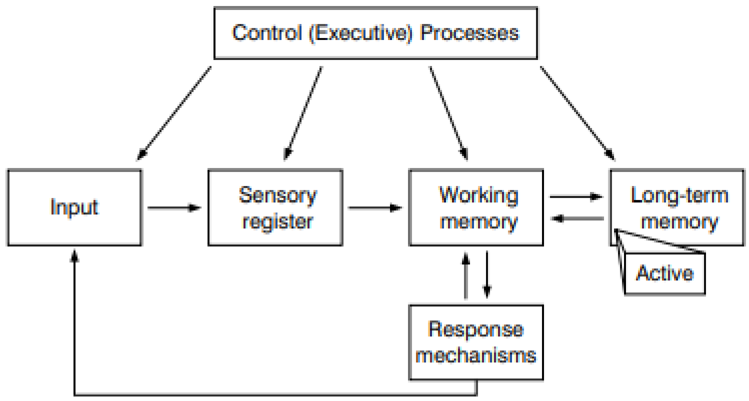

Figure 1: Information Processing Model of Learning and Memory

The sensory register transfers information to short-term memory (STM). STM is a working memory (WM) and corresponds roughly to awareness, or what one is conscious of at a given moment. WM is limited in capacity. Miller (1956) proposed that it holds seven plus or minus two units of information. A unit is a meaningful item: a letter, word, number, or common expression (e.g., “bread and butter”). WM also is limited in duration; for units to be retained in WM they must be rehearsed (repeated). Without rehearsal, information is lost after a few seconds (Schunk, 2012). While information is in WM, related knowledge in long-term memory (LTM), or permanent memory, is activated and placed in WM to be integrated with the new information.

It is debatable whether information is lost from LTM (i.e., forgotten). Some researchers contend that it can be, whereas others say that failure to recall reflects a lack of good retrieval cues rather than forgetting (Schunk, 2012).

Regardless of theoretical perspective, researchers agree that information remains in LTM for a long time.

Control (executive) processes regulate the flow of information throughout the information processing system. Rehearsal is an important control process that occurs in WM. For verbal material, rehearsal takes the form of repeating information aloud or sub vocally (Schunk, 2012). Other control processes include coding (putting information into a meaningful context, imaging (visually representing information), implementing decision rules, organizing information, monitoring level of understanding, and using retrieval, self-regulation, and motivational strategies.

One of the most consistent research findings is that when people have a list of items to learn, they tend to recall best the initial items (primacy effect) and the last items (recency effect). According to the two-store model, initial items receive the most rehearsal and are transferred to LTM, whereas the last items are still in WM at the time of recall. Middle items are recalled the poorest because they are no longer in WM at the time of recall (having been pushed out by subsequent items), they receive fewer rehearsals than initial items, and they are not properly stored in LTM.

Research suggests, however, that learning may be more complex than the basic two-store model stipulates (Baddeley, 1998). One problem is that this model does not fully specify how information moves from one store to the other. The control processes notion is plausible but vague.

2.15 Summary

The above review of past research studies on the technology integration pointed to a number of implications that can be drawn. The review of literature reported different effects of simulations on different types of knowledge. Some studies showed that simulations had a significant impact on factual knowledge (Adams *et al*., 2008), others on conceptual knowledge (Tambade & Wagh, 2011) and others on procedural knowledge (Finkelstein *et al*., 2005; Podolefsky, Perkins & Adams, 2010). In some cases, simulations had a positive impact on 2 types of knowledge (McKagan *et al*., 2008; Kollöffel & de Jong, 2013).

Furthermore, simulations also had different effects on students of different abilities. In some studies, students of high cognitive abilities benefited the most from simulations (Chang *et al*., 2008), while in other studies, students of moderate cognitive abilities took advantage from the simulations the most (Yildiz & Atkins, 2016; Adegoke & Chukwunenye, 2013).

Taking the findings reported from these previous studies, the present study stands out by focusing on how simulations affect students' performance in general, and by highlighting the impact of computer simulations on different knowledge dimensions (factual, conceptual and procedural knowledge) and on students of different academic levels in particular.

CHAPTER THREE

METHODOLOGY

3.0 Overview

The study aimed at examining the consequence of computer simulation instructional approach on Cambridge Lower Secondary School students' performance in biology. This chapter is concerned with the various aspects of the research methodology adopted by the researcher. It contains a detailed description of the research design, population and sampling techniques, research instruments, procedure for data collection and analysis. The validity and reliability of the research instruments, as well as the intervention activities rolled out for the research participants were also presented in this chapter of the report.

3.1 Research Design

The study was action research, designed to enhance students' performance in cell biology at Kent International School. Action research design was chosen amidst other research design methods available to the researcher because it makes for practical problem-solving as well as expanding scientific knowledge, enhances the competencies of participants and is undertaken directly in situ (Cohen, Manion & Morrison, 2012). According to Bjønness and Johansen (2014), action research is designed to bridge the gap between theory and what is practiced in the field of education. Action research is done to improve the educational methods in the classroom through interventions while learning from the outcome of the resulting changes. Action research aims to contribute to the practical concerns of the people in an immediate problematic situation and to further the goals of social science simultaneously.

This study involved three main stages. Pre-intervention stage, intervention stage and post-intervention stage. The pre-intervention stage was used to identify and gather information about the problem. The intervention stage involved the use of computer simulations to conduct series of lessons on cell biology. Six lessons were conducted over six weeks. The post-intervention stage was designed to evaluate the effectiveness of the intervention used. Students were made to respond to a Standardised Achievement Test in Biology [SATiB]. Students' responses to the test items were analysed and discussed. The design of the study is summarised in Figure 2.

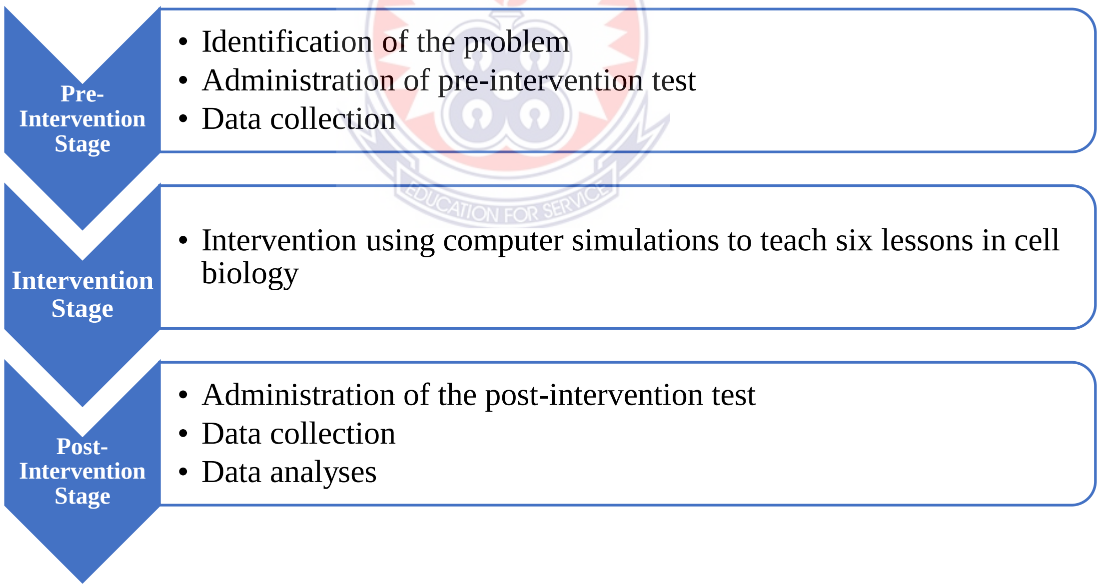

Figure 2: Research Design

3.1.1 Research approach

This study adopted the quantitative research approach. Quantitative research methods emphasise the objective measurement and statistical, mathematical or numerical analysis of data collected through polls, questionnaires and tests or by manipulating pre-existing statistical data using computational techniques (Creswell, 2013). To Cohen *et al*. (2018), quantitative research focuses on gathering numerical data and generalising it across groups of people or explaining a particular phenomenon. These are the focus of this study, hence the approach.

3.2 Target Population of Study

The researcher designed the study to examine the consequence of computer simulations on the academic performance of Cambridge Lower Secondary School science students in the concept of cell biology. In effect, all students studying biology as part of their science programme in Kent International Cambridge school formed the target population of this study. According to Cohen *et al*. (2018), a target population is the group of subjects to whom the findings of a study would be generalised.

3.2.1 Accessible population

The accessible population of the study included all grade eight (8) students studying biology as part of their science programme in Kent International School. An accessible population (Creswell, 2013) is the group of subjects accessible to the researcher and from which the research sample is selected.

3.3 Research Sample and Sampling Technique

An intact class consisting of thirty-six (36) grade eight (8) science students was purposively selected to form the sample of the study. The rationale for the choice of purposive sampling technique was to avert the possibility of distracting normal lessons. In order to ensure effective and efficient implementation of the intervention, the mentioned target group was selected because these students have studied biology for almost two years and therefore could make meaningful contributions to the study. Studying an entire population of the school can be cumbersome hence a need to select a specific form to represent the population. The selection of a representation of the population is called sampling and the representation of the population is called sample (Creswell, 2013). Students included in the sample of this study were thirteen (13) to fourteen (14) years old. Twenty (20) of the thirty-six (36) participants were males whereas the remaining sixteen (16) were females.

3.4 Research Instruments

Collection of data for analyses to answer research questions, or to test hypotheses require the use of some instruments; these are the instruments for data collection. Two instruments, a questionnaire and test items were used to collect data for analyses. Both the tests and questionnaires were constructed by the researcher and tested for validity and reliability.

3.4.1 Tests

Standardised Achievement Tests in Biology [SATiB] were constructed and used by the researcher to collect data before and after the study. These tests were used to determine the performance of the thirty-six research participants comprising the sample before and after the intervention. The test items covered the content of cell biology in Cambridge Lower Secondary School science syllabus. Tests comprised 40 multiple choice items focused on five (5) categories of the Bloom's Taxonomy; remember, understand, apply, analyse and evaluate. Figure 3 summarises the levels of Bloom's Taxonomy espoused in the construction of the SATiB.

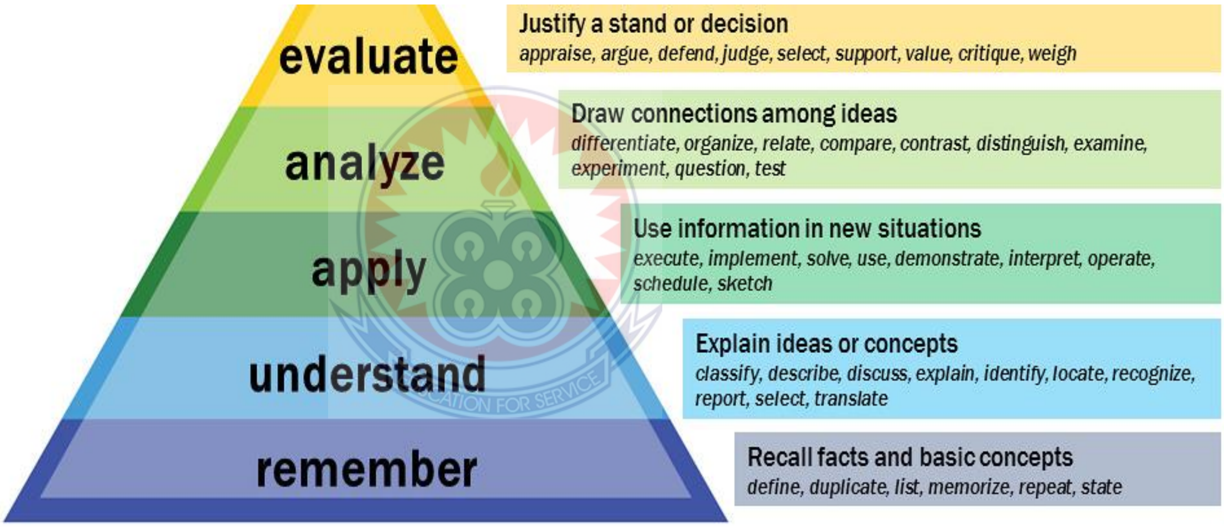

Figure 3: Levels of Bloom's Taxonomy Used to Construct SATiB

Four alternative options were provided for each item. Both the pre- and post-SATiB were equivalent in terms of number of items and difficulty. However, item arrangements had changed in the post-SATiB.

3.4.2 Questionnaire

Another instrument used for data collection was the questionnaire. The questionnaire was used to sample views from the students who participated in this study on the effect of computer simulations on their interest in cell biology. Both open-ended and close-ended questions were used in this instrument. The questionnaire was divided into four parts. Part one of the questionnaire introduces the respondents to the purpose of the questionnaire, the content of the questionnaire, how to respond to the items in the questionnaire and also the confidentiality with which data collected will be treated. Part two of the questionnaire sought demographic data from the respondents, this excludes names and personal addresses to ensure the confidentiality and non-traceability of the data collected. The third part of the questionnaire sought information about the impact of computer simulations on the interest of the students in cell biology. This section also sought the perception of the respondents on the effectiveness of computer simulations in the teaching and learning of biology. Under part four of the questionnaire, the views of the students on how the use of computer simulations to teach cell biology influenced their attitude towards learning of biology was sought.

The questionnaire was a Likert-type questionnaire designed and administered by the researcher.

3.5 Validation of Test

A committee, which was composed of professional biology teachers as well as the researcher's thesis advisor supervised and reviewed the test items to ensure content and face validity. All the items in the tests covered the text material taught to the participants during the intervention. Additionally, Table of Specifications [TOS] was used to construct the test items. Table 1 illustrates this.

Table 1: Table of Specification [TOS]

Ability/ Topic	Lesson Duration (in hours)	Cognitive Knowledge (Remember)	Cognitive Comprehension	Cognitive Application	Cognitive Analysis	Cognitive Evaluation	Total
Cell Functions	1.5	2	2	2	2	2	10
Cell Cycle	1.5	1	3	2	2	2	10
Transport in Cells	1.5	1	2	3	2	2	10
Protein Synthesis	1.5	1	3	1	2	3	10
Total	**6**	**5**	**10**	**8**	**8**	**9**	**40**

3.6 Reliability of Test

A pilot study was conducted in using the test items to determine their reliability. The data obtained from pilot test was subjected to the split half method of estimating reliability. Using the spearman Brow Prophecy formula, the coefficient of reliability ‘r’ for the test was found at 0.88. According to Creswell (2013), reliability coefficient value of 0.90 and up indicates an excellent reliability, 0.80 – 0.89 indicates a good reliability, 0.70 – 0.79 indicates adequate reliability and a reliability coefficient below 0.70 may have limited applicability. Using this interpretation guideline, the test items were accepted as valid and thus used for data collection subsequently.

3.7 Data Collection Procedure

To enhance the understanding of some Cambridge Lower Secondary School students in the concept of cell in biology, action research was planned and carried out in Kent

International Cambridge School in the Greater Accra Region of Ghana. One intervention method; computer simulation instructional approach was applied during the study. Prior to the intervention, a pre-intervention SATiB was administered to the participants of the study to ascertain their entry performance in the concept of cell. For six weeks, participants were given instruction in biology on the concept of cell using computer simulations. After the intervention, a post-intervention SATiB was given to the students. Post-intervention test scores were used as data to quantify the performance of participants as outcome of the intervention. The marks obtained on both the tests were arranged and compared by statistical techniques like descriptive statistics and t-test using the Statistical Package for Social Sciences [SPSS] version 22.

3.8 Analysis of Data

To determine effect of computer simulation on the academic performance of a group of Cambridge Lower Secondary School students of Kent International School, relevant data were obtained from pre- and post-intervention SATiB. These tests provided performance scores with respect to students' knowledge in cell biology. The data were arranged and analysed using statistical analysis software. Descriptive statistics; means and standard deviations were used in analysing the data collected. Significance of difference between the group means of both pre- and post-intervention SATiB scores was determined through t-test at 0.05. Microsoft Excel, version 2019 and statistical package for social sciences (SPSS, version 22) were employed to analyse the data collected.

3.9 Intervention activities

An intervention was designed and carried out to address students' difficulty in understanding cell biology. The intervention was carried out within six weeks during which a computer simulation software was used to teach cell biology. For the purposes of convenience, some lessons were conducted outside of the usual contact hours. The details of each lesson is presented next.

3.9.1 Lesson one: Introduction to cell

Lesson Duration: 60 minutes.

Lesson Objectives: by the end of the lesson, a student will be able to;

1. Define a cell.
2. Differentiate between cell and tissue.
3. List at least four functions of cells.
4. Mention at least five types of animal cells.

Teacher Learner Activities

The lesson was introduced by a short video animation of the animal cell. Next, the teacher used brainstorming to elicit from the students the definition of cell and the difference between a cell and a tissue. The students were then placed in groups and allowed to interact with computer simulation packages on cell under the supervision of the teacher.

Core Points

A cell may be defined as the structural and functional unit of living organisms which is capable of independent existence. Cells vary considerably, in shapes and sizes.

Nerve cells of animals have long extensions. They can be several centimetres in length. Muscle cells are elongated in shape. Egg of the ostrich is the largest cell (75 mm). Some plant cells have thick walls. There is also wide variation in the number of cells in different organisms. A cell is a unit of protoplasm bound by a plasma or cell membrane and possessing a nucleus. Protoplasm is the life-giving substance and includes the cytoplasm and the nucleus. The cytoplasm has in it, organelles such as ribosomes, mitochondria, Golgi bodies, plastids, lysosomes and endoplasmic reticulum. Plant cells have in their cytoplasm, large vacuoles containing non-living inclusions like crystals, and pigments. The bacteria have neither defined cell organelles nor a well-formed nucleus. Despite their many differences, cells have several similar structural features; a cell membrane, a nucleus, and cytoplasm and cell organelles. Red blood cells are an exception because they have no nuclei when mature. The cell membrane forms the outer boundary of the cell and surrounds the cytoplasm, organelles, and nucleus.

Cytologists recognize two basic types of cells, prokaryotic and eukaryotic cells. All cells have three basic parts:

- Cell membrane which limits the cell and gives it shape.
- DNA which may be contained in a nucleus
- Fluid called cytoplasm filling in the space within the cell.

Whether DNA of the cell lies in the cytoplasm or is enclosed within a nuclear membrane, cells may be termed prokaryotic or eukaryotic.

Prokaryotic Cell (Greek _ Pro-before; karyon-nucleus)

These cells do not have a well-organized nucleus. The genetic material is a single molecule of DNA lying in the cytoplasm. Not only is the nuclear membrane absent, cell organelles like mitochondria, lysosomes, endoplasmic reticulum, chloroplast, nucleolus, etc. are also not present in prokaryotic cells. Examples of prokaryotic cells include bacteria cells and blue-green alga

Eukaryotic Cell (Greek _ Eu-true; karyon-nucleus)

In eukaryotic cells, the DNA is enclosed in a nuclear membrane forming a nucleus. The genetic material is made of two or more DNA molecules, which are present as a network of chromatin fibres when the cell is not dividing. Membrane-bound organelles, such as mitochondria, endoplasmic reticulum, lysosome, chloroplast, nucleolus, etc. are present within the cytoplasm. Examples of eukaryotic cells include cells of plants, fungi, protozoa and animals.

Cell Membrane

Each cell has a limiting boundary, the cell membrane, also called plasma membrane or plasma lemma. It is a living membrane, outermost in animal cells but internal to cell wall in plant cells. It is flexible and can fold in or fold out. The cell membrane is made of phospholipids, cholesterol, and proteins. Several models were proposed regarding the arrangement of proteins and lipids in the plasma membrane. The fluid mosaic model is widely accepted. According to the fluid mosaic model, the plasma membrane is composed of a lipid bilayer of phospholipid molecules into which a variety of globular proteins are embedded. Each phospholipid molecule has two ends, an outer head that is hydrophilic i.e., water attracting, and an inner hydrophobic (i.e., water repelling) tail pointing centrally. The protein molecules are arranged in two different ways: Peripheral proteins or extrinsic proteins: these proteins are present on the outer and inner surfaces of the lipid bilayer. Integral proteins or intrinsic proteins penetrate the lipid bilayer partially or wholly.

The phospholipids are di-glycerides, and form a bilayer, or double layer, which makes up most of the membrane. Phospholipids permit lipid-soluble materials to easily enter or leave the cell by diffusion through the cell membrane. The presence of cholesterol decreases the fluidity of the membrane, thus making it more stable. The proteins have several functions: Some form channels or pores to permit passage of materials such as water or ions; others are carrier enzymes or transporters that also help substances enter the cell. Still other proteins, with oligosaccharides on their outer surface, are antigens, markers that identify the cells of an individual as "self." Yet another group of proteins serves as receptor sites for hormones. Many hormones bring about their specific effects by first bonding to a particular receptor on the cell membrane, a receptor with the proper shape. This bonding, or fit, then triggers chemical reactions within the cell membrane or the interior of the cell.

The cell membrane is of particular importance for muscle cells and nerve cells because it carries electrical impulses.

Functions of Cells

Cells are specialised to perform different functions. Bone cells support the bones, red blood cells carry oxygen, nerve cells transmit signals, muscle cells move the body, skin cells protect organs and sex cells enable reproduction.

Levels of Organisation

The human body is organized into structural and functional levels of increasing complexity. Each higher level incorporates the structures and functions of the previous level. The simplest level is the chemical level, and proceed to cells, tissues, organs, and organ systems.

Chemicals

The chemicals that make up the body may be divided into two major categories: inorganic and organic. Inorganic chemicals are usually simple molecules made of one or two elements other than carbon (with a few exceptions). Examples of inorganic chemicals are water (H_2O); oxygen (O_2); one of the exceptions, carbon dioxide (CO_2); and minerals such as iron (Fe), calcium (Ca), and sodium (Na). Organic chemicals are often very complex and always contain the elements carbon and hydrogen. In this category of organic chemicals are carbohydrates, fats or lipids, proteins, and nucleic acids. These organic chemicals are considered the four major classes of biological macromolecules.

Cells

The smallest living units of structure and function are cells. There are many different types of human cells, though they all have certain similarities. Each type of cell is made of chemicals and carries out specific chemical reactions. Somatic cells, which include all body cells other than sex cells, arise from the zygote formed by two sex cells during fertilization. All cells divide and multiply in the embryo, they change in shape and structure depending on which parts of their genetic code is activated. This process is known as differentiation.

Tissues

A tissue is a group of cells with similar structure and function. There are four groups of tissues:

Epithelial tissues—cover or line body surfaces; some are capable of producing secretions with specific functions. The outer layer of the skin and sweat glands are examples of epithelial tissues. Internal epithelial tissues include the walls of capillaries (squamous epithelium) and the kidney tubules (cuboidal epithelium).

Connective tissues—connect and support parts of the body; some transport or store materials. Blood, bone, cartilage, and adipose tissue are examples of this group.

Muscle tissues—specialized for contraction, which brings about movement. Our skeletal muscles and the heart are examples of muscle tissue.

Nerve tissue—specialised to generate and transmit electrochemical impulses that regulate body functions. The brain and optic nerves are examples of nerve tissue.

Organs

An organ is a group of tissues precisely arranged so as to accomplish specific functions. Examples of organs are the kidneys, individual bones, the liver, lungs, and stomach. The kidneys contain several kinds of epithelial, or surface tissues, for their work of absorption. The stomach is lined with epithelial tissue that secretes gastric juice for digestion. Smooth muscle tissue in the wall of the stomach contracts to mix food with gastric juice and propel it to the small intestine. Nerve tissue carries impulses that increase or decrease the contractions of the stomach.

Organ Systems

An organ system is a group of organs that all contribute to a particular function. Examples are the urinary system, digestive system, and respiratory system. The urinary system consists of the kidneys, ureters, urinary bladder, and urethra. These organs all contribute to the formation and elimination of urine. Some organs are part of two organ systems; the pancreas, for example, is both a digestive and an endocrine organ, and the diaphragm is part of both the muscular and respiratory systems. All of the organ systems make up an individual person.

Evaluation

At the end of the first lesson, the following activity was given.

- What are the structures that all cells have in common?
- Draw a detailed sketch of a bacterium and label its parts.

3.9.2 Lesson two: Cellular transport mechanisms

Lesson Duration: 60 minutes.

Lesson Objectives: by the end of the lesson, a student will be able to;

1. Distinguish between diffusion and osmosis using appropriate examples.
2. Use practical examples to differentiate between diffusion and osmosis in cells.
3. Explain the effect of tonicity on plant and animal cells.

Teacher Learner Activities

The teacher introduced the lesson by allowing the learners to interact with computer simulations on cell transport mechanisms. After the interaction, discussion and brainstorming was used to provoke the explanation of the various cell transport mechanisms from the students, as was presented in the computer simulation.

Core Points

Molecules move in and out of a cell through the cell membrane, which forms the boundary of each cell. The cell membrane is selectively permeable to substances, which means that it permits entry and exit of certain molecules only. There are several mechanisms of transport that enable cells to move materials into or out of the cell: diffusion, osmosis, facilitated diffusion, active transport, filtration, phagocytosis, and pinocytosis. Some of these take place without the expenditure of energy by the cells. But others do require energy, often in the form of ATP. Each of these mechanisms is described in the following sections and an example is included to show how each is important to the body.

Diffusion

Molecules move out from their region of higher concentration to the region of lower concentration (that is, with or along a concentration gradient). For example, during respiration, oxygen-laden air in lungs being at a higher concentration moves into blood capillaries having lower concentration of oxygen in them. Such movement of particles or molecules from a region of their higher concentration to a region of their lower concentration is termed diffusion. Diffusion occurs because molecules have free energy; that is, they are always in motion. Imagine a piece of blue dye at the bottom of a glass of water. As the dye dissolves, the dye molecules collide with one another or the water molecules, and the blue colour seems to rise in the glass. These collisions spread out the dye molecules until they are evenly dispersed among the water molecules, and the water eventually becomes entirely blue. The molecules are still moving, but no net change is further observed. Thus, an equilibrium (or steady state) is reached. Diffusion is a very slow process, but may be an effective transport mechanism across microscopic distances.

Osmosis

Osmosis may be simply defined as the diffusion of water through a selectively permeable membrane. That is, water will move from an area with more water present to an area with less water. Another way to say this is that water will naturally tend to move to an area where there is more dissolved material, such as salt or sugar. If a 2% salt solution and a 6% salt solution are separated by a membrane allowing water but not salt to pass through it, water will diffuse from the 2% salt solution to the 6% salt solution. The result is that the 2% solution will become more concentrated, and the 6% solution will become more dilute. The reason it occurs is that when water molecules move to the high-solute side, they tend to loosely cling to the solute molecules. Becoming less mobile, they are not as able to break free and cross back to the low-solute side; there are more water molecules on the low-solute side free to pass through the membrane than there are on the high-solute side. Thus, if the fluids on two sides of a cell membrane differ in the concentration of dissolved matter (and these solutes cannot penetrate the membrane), water tends to move by osmosis from the more dilute to the less dilute side. Osmosis plays a key role in many aspects of homeostasis. For example, blood capillaries absorb fluid from the tissues by osmosis, thereby removing metabolic wastes from the tissues and preventing them from swelling.

The ability of a solution to affect intracellular pressure and volume is called tonicity**.** It is determined by the concentration of solutes, inside the cell and out, that cannot pass through the plasma membrane *(non-permeating solutes)* but drive the cell's gain or loss of water. If the intracellular and extracellular fluids (ICF and ECF) have the same tonicity, they are said to be isotonic with each other. In an isotonic solution, cells gain and lose water at equal rates and cell volume remains constant. But if the ECF has a higher concentration of non-permeating solutes than the ICF, it is hypertonic to the cells and can cause cellular damage and death by drawing water out of them. If the ECF has a lower concentration of non-permeating solutes than the ICF, it is hypotonic to the cells and causes cellular swelling and potentially ruptures them.

Facilitated Diffusion

The word *facilitate* means to help or assist. In facilitated diffusion, molecules move through a membrane from an area of greater concentration to an area of lesser concentration, but they need some help to do this. In the body, our cells must take in glucose to use for ATP production. Glucose, however, will not diffuse through most cell membranes by itself, even if there is more outside the cell than inside. Diffusion of glucose into most cells requires a glucose transporter, which may also be called a carrier enzyme. These transporters are proteins that are part of the cell membrane. Glucose bonds to the transporter, and by doing so changes the shape of the protein. This physical change propels the glucose into the interior of the cell. Other transporters are specific for other organic molecules such as amino acids.

Active Transport

Active transport requires the energy of ATP to move molecules from an area of lesser concentration to an area of greater concentration. Notice that this is the opposite of diffusion, in which the free energy of molecules causes them to move to where there are fewer of them. Active transport is therefore said to be movement against a concentration gradient. An especially important active transport process is the sodium–potassium (Na^+–K^+) pump. Sodium is normally much more concentrated in the extracellular fluid than in the intracellular fluid, and potassium is more so in the intracellular fluid. Yet cells continually pump more Na^+ out and more K^+ into the cell. The Na^+–K^+ pump binds three sodium ions from the intracellular fluid and ejects them from the cell, then binds two potassium ions from the extracellular fluid and releases these into the cell. It repeats the process over and over, using one ATP molecule for each cycle. The Na^+–K^+ pump plays roles in controlling cell volume (water follows Na^+ by osmosis); generating body heat (ATP consumption releases heat); maintaining the electrical excitability of your nerves, muscles, and heart; and providing energy for other transport pumps to draw upon in moving such solutes as glucose through the plasma membrane.

Filtration

The process of filtration also requires energy, but the energy needed does not come directly from ATP. It is the energy of mechanical pressure. Filtration means that water and dissolved materials are forced through a membrane from an area of higher pressure to an area of lower pressure. In the body, blood pressure is created by the pumping of the heart. Filtration occurs when blood flows through capillaries, whose walls are only one cell thick and very permeable. The blood pressure in capillaries is higher than the pressure of the surrounding tissue fluid. In capillaries throughout the body, blood pressure forces plasma (water) and dissolved materials through the capillary membranes into the surrounding tissue spaces. This creates more tissue fluid and is how cells receive glucose, amino acids, and other nutrients. Blood pressure in the capillaries of the kidneys also brings about filtration, which is the first step in the formation of urine.

Vesicular Transport

All of the processes discussed up to this point move molecules or ions individually through the plasma membrane. In vesicular transport**,** however, cells move larger particles or droplets of fluid through the membrane in bubble-like vesicles. Like active transport, all forms of vesicular transport require ATP. All vesicular processes that bring matter into a cell are called endocytosis. There are three forms of endocytosis: phagocytosis, pinocytosis, and receptor-mediated endocytosis.

Evaluation

Answer these questions from memory.

Which membrane transport processes get all the necessary energy from the spontaneous movement of molecules?

Which ones require ATP as a source of energy?

Which processes are carrier-mediated? Which ones are not?

3.9.3 Lesson three: synthesis of proteins in cells

Lesson Duration: 60 minutes.

Lesson Objectives: by the end of the lesson, a student will be able to;

1. Describe the process of transcription
2. Describe the process of translation

Teacher Learner Activity

The teacher introduced the lesson by allowing the learners to interact with computer simulations on protein synthesis in cells. After the interaction, discussion and brainstorming was used to provoke the explanation of the various stages involved in the synthesis of proteins from the students, as was presented in the computer simulation.

Core Points

One of the most significant activities of a cell is to produce proteins, the proteins of a cell can be for internal structural use, such as proteins of the cytoskeleton and cellular membranes; they include enzymes that control the cell's internal metabolism; and in many cases they are secreted from the cell to serve elsewhere, as in the case of digestive enzymes, antibodies, and some hormones such as insulin and growth hormone. DNA in the nucleus contains codes (genes) for how to construct the needed proteins. Synthesis begins with making a small copy of a gene, called messenger RNA (mRNA). This usually migrates into the cytoplasm, where ribosomes read the code and assemble amino acids in the right order to make that protein. The step from DNA to mRNA is called transcription, and the step from mRNA to protein is called translation. The transcription and translation of the genetic code in DNA into proteins require RNA. DNA is found in the chromosomes in the nucleus of the cell, but protein synthesis takes place on the ribosomes in the cytoplasm. Messenger RNA (mRNA) is the intermediary molecule between these two sites.

Transcription

Protein synthesis begins with transcription in the cell's nucleus. At the site of a particular gene, an enzyme, DNA helicase unzips the double helix of DNA and exposes the gene's nitrogenous bases. Another enzyme, DNA polymerase reads these bases and creates a parallel molecule of messenger RNA (mRNA), which is that is a complimentary copy of half the DNA gene. Where the enzyme finds a thymine (T) on the DNA, it adds the complementary base adenine (A) to the mRNA. Where it finds a guanine (G) on the DNA, it adds cytosine (C) to the mRNA. Where it finds adenine, however, it adds uracil (U) to the mRNA; because RNA does not contain any thymine, but substitutes uracil for this base. Therefore, if the enzyme had read a DNA base sequence of TACCGTCCA, it would produce a complementary mRNA sequence of AUGGCAGGU. A typical mRNA is several hundred bases long and some are up to 10,000. The mRNA is "edited" in the nucleus to remove some noncoding segments. The coding segments are spliced together to make a mature, coding mRNA molecule, which is then usually exported from the nucleus, through a nuclear pore, into the cytoplasm.

Translation

The next step of protein synthesis is translation**.** This is where ribosomes enter the story. They are composed of ribosomal RNA (rRNA) and enzymes, forming a complex that can read the mRNA and translate its code into the amino acid sequence of a protein. The genetic code is in the form of codons—three-base segments of mRNA. There are 64 of these, most of which stand for a particular amino acid to be inserted into a protein. For example, the sequence AUG represents methionine, GCA represents alanine, and GGU represents glycine.

Each time the ribosome reads a particular codon, it binds a smaller RNA molecule called transfer RNA (tRNA) with a complementary base series called an anticodon. For example, if the ribosome reads GGU on the mRNA, it binds a tRNA with anticodon CCA. Each tRNA brings a particular amino acid with it, which the enzymes in the ribosome add to the growing protein chain. The ribosome then reads the next codon, adds the next amino acid, and so on. When it reaches a special base sequence called a stop codon, like the period at the end of a sentence, the protein is finished. The ribosome releases the new protein and detaches from the mRNA.

Evaluation

Answer the following question from memory.

Name three organelles involved in protein synthesis and describe their respective roles. Explain the difference between transcription and translation and state where in the cell each of these occurs.

3.9.4 Lesson four: cell division

Lesson Duration: 60 minutes.

Lesson Objectives: by the end of the lesson, a student will be able to describe the process of cell division.

Teacher Learner Activity

The teacher introduced the lesson by allowing the learners to interact with computer simulations on cell division. After the interaction, discussion and brainstorming was used to provoke the explanation of the various stages involved in the division of cells from the students, as was presented in the computer simulation.

Core Points

A single cell divides many times and forms a multi celled organism. Unicellular bacteria and protozoa divide and increase in number. The injured tissues are replaced by new cells through cell division. Thus, cell division is one of the most important activities in all organisms. Majority of cells in a multicellular organism grow and then can divide. However, the cells like the nerve and muscle cells of animals and guard cells of plants do not divide. Cell division is the process by which a cell reproduces itself. The process of cell division is almost same in all organisms. A cell passes through phases of growth after which are able to duplicate their chromosomes before they divide. These phases in the life of a cell constitute the cell cycle. There are two types of cell division, mitosis and meiosis. Although both types involve cell reproduction, their purposes are very different.

The Cell Cycle

You can use the term mother or parent cell for the cell that undergoes division and the daughter cells for the ones that are the result of this division. Before each daughter cell undergoes division, it must grow to the same size as its mother cell. We can distinguish two main phases in the life of a cell. Interphase - Non-dividing period (Growth phase) and Dividing phase - Also called M-phase (M for mitosis or meiosis).

Interphase

The interval between two successive cell divisions is termed interphase (phase at which the cell is not dividing). It is the longest period in the cell cycle. The interphase is subdivided into three main periods - G1, S and G2. G1 (Gap-1) Phase i.e. First phase of growth – This is the longest phase. Lot of protein and RNA are synthesised during this phase. S or synthetic Phase - a period in which a cell replicates its DNA, doubling it in preparation for the upcoming cell division. A chromosome contains a single double helical strand of DNA molecule. After S-phase each chromosome becomes longitudinally double except at centromere, and thus, it has two molecules of DNA and two chromatids. Thus, each of Life chromatid contains one molecule of DNA. The two chromatids are joined by a centromere (which does not divide at this stage) to form a single chromosome. G2 (GAP 2) phase - More protein including the histones are synthesised in this phase. Cytoplasmic organelles such as mitochondria and Golgi bodies get duplicated. Centriole also divides into two centrioles contained in a single centrosome.

Kinds of Cell Division

There are two kinds of cell division- mitotic cell division and meiotic cell division. Mitotic cell division is for growth and replacement of older cells by new cells wherein the two daughter cells are identical and similar to mother cell in all respects. Mitotic cell division occurs in haploid as well as diploid cells. Meiotic cell division occurs in the gonads for sexual reproduction to produce gametes. The resultant cells, egg (in female) and sperms (in male), possess half the chromosome number of that present in the parent cell. Meiotic cell division takes place only in diploid cells responsible for production of haploid spores or gametes.

Evaluation

Name the two kinds of cell division and state the significance of each.

3.9.5 Lesson five: cell division (mitosis)

Lesson Duration: 60 minutes.

Lesson Objectives: by the end of the lesson, a student will be able to describe the processes of mitosis.

Teacher Learner Activity

The teacher introduced the lesson by allowing the learners to interact with computer simulations on mitosis. After the interaction, discussion and brainstorming was used to provoke the explanation of the various stages involved in mitosis from the students, as was presented in the computer simulation.

Core Points

Mitosis is divided into 4 phases or stages termed as Prophase, Metaphase, Anaphase and Telophase. These phases refer to the changes taking place in the nucleus.

Prophase**:** It shows three sub phases:

Early prophase: Centriole divides and each of the two centrioles start moving towards opposite poles of the nucleus of the dividing cell. Chromosomes appear as long threads, and start coiling. Nucleus enlarges and becomes less distinct.

Middle prophase: Chromosome condensation is complete and they become short and thick**.** Each chromosome is made up of two chromatids held together at their centromeres. Each chromatid contains newly replicated daughter DNA molecule.

Late Prophase: Centrioles reach the opposite poles of the dividing cell. Some spindle fibres extend from pole to the equator of the dividing cell. Nuclear membrane disappears**.** Nucleolus is not visible.

Metaphase

Chromosomes are brought towards the equator of the cell, with the help of spindle fibres**.** Each chromosome becomes attached to the two spindle fibres by centromere. Whereas each centromere is joined to the opposite poles. The sister chromatids are not yet separated because the centromere has not divided.

Anaphase

Centromeres of all the chromosomes divide and then each chromatid becomes a chromosome. Spindle fibres contract and pull the centromeres to the opposite poles. As the chromosomes are pulled by spindle fibres to opposite poles by their centromeres, they acquire various shapes such as V, J or I depending upon the position of centromere. Half the number of chromosomes move towards one pole and the other half to the opposite pole. Cytokinesis begins as the cleavage furrow starts from the periphery towards the centre in animal cells, and in plants, cell plate appears in the centre that grows centrifugally towards periphery.

Telophase

Chromosomes uncoil to form a chromatin network as in the parent nucleus. New nuclear membrane is formed around each daughter nucleus. Nucleolus reappears again in each newly formed daughter nucleus.

Cytokinesis

It is the process of the division of cytoplasm of a dividing cell into two. It is initiated in the beginning of telophase and is completed by the end of telophase. The mechanism of cytokinesis is different in plant and animal cells. In an animal cell, invagination of plasma membrane proceeds from the periphery of the cell towards the interior. In plant cell phragmoplast (cell plate) begins to form in the centre of cell and then expands towards the periphery.

Significance of Mitosis

It is an equational division, and the two newly formed daughter cells are identical in all respects. They receive the same number and kind of chromosomes as were in the mother cells. It is the only mode of reproduction in unicellular organisms. It is the process by which growth takes place in multicellular animals and plants by constantly adding more and more cells. It also plays a role in repair during growth, for example in wound healing, regeneration of damaged parts (as in the tail of lizard), and replacement of cells lost during normal wear and tear (as the surface cells of the skin or the red blood cells).

Evaluation

1. Name the stage of cell cycle during which chromatin material is duplicated.

2. Is the number of chromosomes reduced in the daughter cells during mitosis? yes/no?

3. Name the stage in nuclear division described by each of the following sentences:

(i) disappearance of the nuclear membrane

(ii) The nuclear membrane and nucleolus reappear

(iii) The centromere divides and the chromatids move to opposite poles due to the shortening of spindle fibres

(iv) The chromosomes arrange themselves at the equatorial plane of the spindle with the spindle fibres attached to the centromeres.

3.9.6 Lesson six: cell division (meiosis)

Lesson Duration: 60 minutes.

Lesson Objectives: by the end of the lesson, a student will be able to describe the processes of meiosis.

Teacher Learner Activity

The teacher introduced the lesson by allowing the learners to interact with computer simulations on meiosis. After the interaction, discussion and brainstorming was used to provoke the explanation of the various stages involved in meiosis from the students, as was presented in the computer simulation.

Core Points

meiotic division is also known as 'reduction division'. But why this name? This is because, in this kind of cell division the normal chromosome number of the mother cell is reduced to half in daughter cells. The normal chromosome number in human being is 46 (23 pairs), this is called the diploid number, but as a result of meiosis in ovary and testes this number is halved to 23 in daughter cells, called the haploid number.

Where does it occur? It occurs in reproductive cells, e.g., in the testes of male and in the ovaries of female animals; and in plants, in the pollen mother cell of the anthers (male organs) and in the megaspore mother cells of the ovary (female organ) of the flowers.

Why does it occur? In meiosis the chromosome number is reduced to half so that when doubled at fertilisation (zygote formation) during the reproduction it once again becomes restored to the diploid state. The number of chromosomes remains constant in a species generation after generation. Cells divide mitotically in the organisms that reproduce vegetatively/asexually. Thus, there is no change in the number of chromosomes, but sexually reproducing organisms form gametes such as sperms in males and ova in females. The male and female gametes fuse to form the zygote which develops into a new individual. If these gametes were, produced by mitosis, the offspring developing from zygote then would have double the number of chromosomes in the next generation. Every living organism has a definite number of chromosomes in its body cells. e.g., onion cell-16; potato-48; horse-64; man-46. Therefore, to keep the chromosome number constant the reproductive cells of the parents (ovaries and testis in animals, and pollen mother cells in anthers and megaspore mother cells in the ovules inside the ovary in plants) divide through meiosis.

How does meiosis occur? Meiosis is characterized by two successive divisions of the nucleus (meiosis I and II) and cytoplasm, whereas the chromosomes divide only once. The interphase which precedes the onset of meiosis is similar to the interphase which precedes mitosis. At S-phase, the DNA molecule of each chromosome duplicates to give rise to two DNA molecules and hence two chromatids are found in one chromosome attached to a single centromere.

Meiosis-I

Like mitosis, Meiosis-I also consists of four stages; Prophase-I, Metaphase-I, Anaphase-I and Telophase-I.

Prophase-I

The Prophase-I of Meiosis-I is much longer as compared to the prophase of mitosis. It is further sub-divided into the following five sub-stages:

Leptotene

The chromosomes become distinct and appear as long and thin threads bearing fine beads due to condensation (coiling of DNA) at specific points called chromomeres.

Each chromosome consists of two chromatids held together by a centromere but these are not easily visible. Nuclear membrane and nucleolus are distinct.

Zygotene

Chromosomes continue coiling and become shorter and thicker. Similar or homologous chromosomes start pairing from one end. This pairing is known as synapsis**.** Each pair of homologous chromosomes is called a bivalent. Nuclear membrane and nucleolus are distinct.

Pachytene

The chromosomes become shorter and thicker due to further coiling. Each paired unit called a 'bivalent' shows four chromatids hence bivalents are also known as tetravalent. Crossing-over occurs at the end of pachytene i.e., break and exchange of parts (genes) occurs between non-sister chromatids (chromatids of a homologous pair) The point of interchange and re-joining is known as chiasma (plural-chiasmata) or the point of crossing over.

Diplotene

Chromosomes continue coiling further and become shorter. The centromeres of homologous chromosomes start repelling each other. The two non-sister chromatids of a homologous pair of chromosomes remain, attached at one or two points, the chiasmata. Nucleolus and nuclear membrane become indistinct. It is at the chiasmata that exchange of segments of non-sister chromatids (genes) between homologous chromosomes has taken place. The process of gene exchange is known as genetic recombination.

Diakinesis

The bivalents become the shortest and thickest due to maximum coiling. The centromeres and non-homologous parts of homologous chromosomes of a bivalent move apart due to repulsion from each other. Consequently, the bivalents acquire various configurations such as O, X or 8, depending upon the number of chiasmata per bivalent. Nuclear membrane and nucleolus disappear. Spindle formation is completed.

Metaphase-I

The bivalents arrange themselves at the equatorial plate. The homologous chromosomes arrange in such a way that all maternal or all paternal chromosomes do not get attached to same pole. In other words, some maternal and some paternal chromosomes are joined to each pole. The spindle fibres are attached at the centromere of the chromosomes. One centromere of a bivalent is joined to one pole and second centromere is joined to the opposite pole by the separate spindle fibres.

Anaphase-I

The spindle fibres shorten. The centromeres of homologous chromosomes are pulled along by the spindle fibres towards the opposite poles (no division of centromere) Thus, half of the number chromosomes (each with two chromatids) of the parent cell go to one pole and the remaining half to the opposite pole. Each set of chromosomes that moves to one pole consists of a mixture of paternal and maternal chromosome parts (new gene combination). This is the basic reason for mixing of maternal and paternal genes in the products of meiosis.

Telophase-I

The separated chromosomes uncoil in the newly formed daughter nuclei. The daughter nuclei have half the number of centromeres as compared to that in the parent nucleus. But, since each centromere has two chromatids, amount of DNA at the two poles at Telophase-I is same i.e., 2n (diploid as in the parent nucleus wherein the chromosomes had duplicated at S-phase, thus amount of DNA in the dividing cell up to anaphase I was 4n) The daughter cells now have half the amount of DNA as compared to that at Anaphase-I, that is 2n. The nucleus reappears and nuclear membrane forms. The daughter nuclei enter into the second meiotic division.

Second Meiotic Division has the same four stages; Prophase II, Metaphase II, Anaphase II and Telophase II.

Prophase II

The chromosomes shorten and chromatids become distinct. The two chromatids of each chromosome are attached to the single centromere. Formation of spindle starts. Nucleolus and nuclear membrane begin to disappear.

Metaphase II

The chromosomes arrange themselves along the equator. Formation of spindle apparatus is completed. The centromere of each chromosome is attached by two spindle fibres to the opposite poles.

Anaphase II

The centromere in each chromosome divides so that each chromatid has its own centromere and each chromatid is now a complete chromosome. The chromatids get their respective centromere and become daughter chromosomes and begin to move towards the opposite poles due to contraction of spindle fibres.

Telophase II

On reaching the poles, the chromosomes organize themselves into haploid daughter nuclei. The nucleolus and the nuclear membrane reappear. Each of the four daughter nuclei has half the number of chromosomes (n) as well as half the amount of DNA as compared to the parent nucleus (2n).

Cytokinesis

This may occur in two successive stages, once after meiosis I and then after meiosis II, or in some instances it occurs only after meiosis II. Thus, after meiotic cell division four haploid cells are formed.

Significance of Meiosis

It helps to maintain constant number of chromosomes in different generations of a species undergoing sexual reproduction. Meiosis occurs during gamete formation (gametogenesis) and reduces the number of chromosomes from diploid (2n) to haploid (n) in the gametes. These haploid gametes fuse to form diploid zygote during fertilization. The diploid zygote develops into a normal diploid individual. Meiosis establishes new combination of characters due to mixing of paternal and maternal chromosomes and crossing over during prophase I. As a result, the progeny inherits the traits of both the mother and the father in new gene combinations.

3.10 Ethical Considerations

Ethics in educational research are those issues that are related to how educational researchers conduct themselves and the consequences of these on the people who participate in their research (Creswell, 2013). Ethical clearance for the conduct of this study was granted by Graduate School, University of Education, Winneba. The researcher made all prospective participants aware of the purpose of the study and their rights as participants. Additionally, only participants who signed up willingly were used for the study. The anonymity of participants was ensured in this study; there was no manner in which participants could be identified by name or by any other means during and after the study since those details were not sought for. The confidentiality of the data collected and how data was handled was entirely made known to the participants of the study. Participants were also free to exit the study at any point.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.0 Overview

This chapter deals with analysis of data and discussion of the results and findings from the study. The chapter comprises three sections. The first section presents the demographic characteristics of the thirty-six (36) students who took part in the study. The second section presents the findings based on research questions and the concluding section presents the discussion of the findings.

4.1 Demographic Characteristics

This section presents the demographic characteristics of the thirty-six (36) students who participated in this study. Thirty-six students participated in the study. Out of this number, sixteen (16) of them, representing forty-four percent (44%) were females whereas twenty (20) of the participants, representing fifty-six percent (56%) were male students.

Figure 4 presents the age distribution of the respondents of this study.

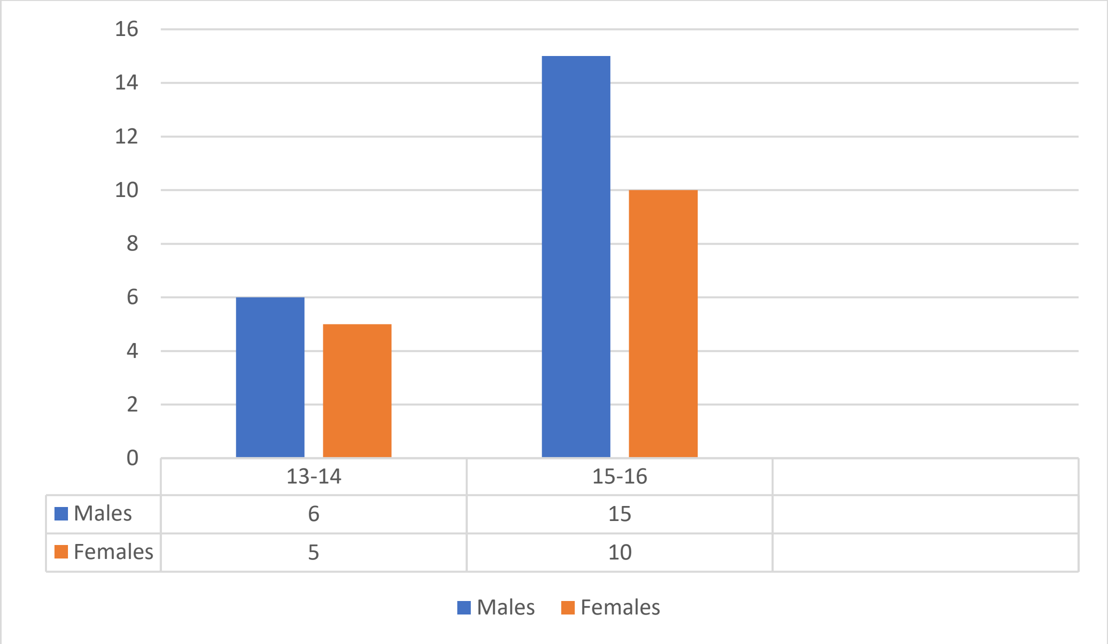

Figure 4 : Age distribution of the respondents

Eleven students, consisting of six males and five females were 13 to 14 years while 25 respondents, consisting of 15 males and 10 females were 15 and 16 years (Figure 4).

The results that emanated from this study are presented next according to the research questions.

4.2 Results

The data from this study are presented in this section. The data is presented according to the research questions posed in the first chapter of this report.

4.2.1 Research question one

RQ1: What is the performance *of students in biology before and after the use of computer simulation instructional strategy to teach biology?*

This research question sought to compare the performance of the students on standardised biology tests before and after they were taught biology using the computer simulation instructional strategy. Before the intervention took place, all participants of the study were subjected to a pre-intervention test in order to check their background knowledge about “Cell Biology”. Data from the pre-intervention test is divided into two parts as high achievers and low achievers. After the intervention, a post-intervention test was conducted. Tables 2 shows the means between the pre-intervention test and the post-intervention test of the research respondents. The tables also indicate standard deviation differences between the pre-intervention test and the post-intervention test. In addition, the number of respondents in each case was thirty-six (36).

From Table 2, it could be seen that the mean performance of the students on the pre-intervention test (12.58) is less that their mean performance on the post-intervention test (23.32). at the time the students took the pre-intervention test, they were not exposed to computer simulations. Their mean performance of 12.58 on the pre-intervention test was found to be below the average score of 15.0. after computer simulations were used continuously for six weeks to teach biology, the students were found to perform better on the post-intervention test. It could be inferred from the results that the computer simulations used to teach biology positively influenced the performance of the students on the post-intervention test.

Table 2: Comparison of Students' Performance on Pre- and Post-intervention Tests

Test type	N	Mean	SD	SE of mean
Pre-intervention test	36	12.58	2.98	0.40
Post-intervention test	36	23.32	3.17	0.43

N = number ****SD = standard deviation*** ****SE = standard error***

The researcher sought further to examine whether the performance of the students on the pre-intervention test differ significantly from their performance on the post-intervention test. To this end, a paired sample t-test was conducted on the results. The outcome of the t-test is presented in Table 3.

To pass judgement on the first null hypothesis, the results of the pre- and post-intervention tests were subject to the t-test. Null hypothesis one was tested at an alpha level of 0.05. Table 3 shows that the p-value (0.00) is less than the alpha value (0.05). This could be interpreted to mean that the difference between the performances of the students on the pre- and post-intervention tests is statistically significant. Judging from the means, it is clear that the difference is in favour of the post-intervention test. Hence, the null hypothesis stating that there is no statistically significant difference between the performance of students before and after using computer simulation instructional strategy to teach biology was rejected.

In effect, it could be inferred from the results that computer simulation instructional strategy had a positive impact on the academic performance of students in biology.

Table 3: Paired Sample t-Test Comparing Pre- and Post-intervention Test Scores

Test type	Observation	DF	Mean	t Stat	P-value
Pre-intervention test	36	35	12.58	9.57	0.00
Post-intervention test			23.32		

DF = degree of freedom   *t Stat = t statistic   P-value = probability value

4.2.2 Research question two

What is the effect of computer simulation instructional strategy on the performance of different ability level learners taught biology using computer simulations?

This research question sought to compare the performance of low achievers and high achievers before and after the intervention. Prior to the intervention, a pre-intervention test was administered to the respondents of this study. Students have been classified into three (3) ability levels, High Level (HL), Medium Level (ML) and Low Level (LL) based on their mean scores in biology on different types of assessment over a period of 3 weeks, including Homework, Classwork, Laboratory reports and Quizzes. Those students who scored below the average mark were classified as the low achievers, those who scored the average mark were classified as medium achievers and those students who scored above the average mark were classified as the high achievers. The performances of these different level ability learners were compared again after the intervention.

In order to compare the performances of the students on the pre- and post-intervention tests, a one- way analysis of variance (one-way ANOVA) is used. Table 4 features the descriptive statistics that compare the performances of the students on the pre- and post-intervention tests. The post-intervention test has a higher mean score (M = 23.32) than the pre-intervention test (M = 12.58). In addition, the distribution of scores around the mean is slightly lower in the pre-intervention test (SD = 2.98 and SE = .40) compared to the post-intervention test (SD = 3.17 and SE = .43).

Table 4: Descriptive Statistics of Pre- and Post-intervention Test Scores

Test type	N	Mean	SD	SE of mean
Pre-intervention test	36	12.58	2.98	0.40
Post-intervention test	36	23.32	3.17	0.43
Total	36	19.97	2.99	0.38

N = number ****SD = standard deviation*** ****SE = standard error***

Results from the one-way ANOVA presented in Table 5 show that the difference between the mean score of the pre-intervention test and that of the post-intervention test is statistically significant. Since the F test statistic (6.74) in the ANOVA table is greater than the F critical value (3.35) in the F distribution table, it means that there is sufficient evidence to say that there is a statistically significant difference between the mean test scores of the two tests.

Table 5: One-way ANOVA for Pre- and Post-intervention Test Scores

Source	Sum of Squares (SS)	df	Mean Squares (MS)	F Stat.	F Crit.
Treatment	147.29	1	147.29	6.74	3.35
Error	1987.61	34	21.84		
Total	2134.90	35			

df = degree of freedom ****F Stat. = F statistic*** ****F Crit. = F critical value***

Test of hypothesis two

There is no statistically significant difference between the performance of different ability learners on assessment scores before and after they were taught biology using computer simulations.

A univariate Analysis of Variance (two-way ANOVA) was conducted to compare the pre- and post-intervention test scores of the of the students, taking into consideration their ability levels. Table 6 shows that the high ability students performed only slightly better on the post-intervention test (M = 25.89, SD = 2.09) than they did on the pre-intervention test (M = 25.44, SD = 1.88). However, the difference between the performance of medium ability students on the post-intervention test (M = 22.00, SD = 1.84) and the pre-intervention test (M = 18.78, SD = 3.70) is greater than the one observed for high ability students. The latter result is also observed when comparing the performance of low ability students on the post-intervention test (M = 15.45, SD = 2.50) to their performance on the pre-intervention test (M = 12.40, SD = 1.90).

Table 6: Descriptive Statistics of Test Scores Based on Student Abilities

Test	Ability of Students	N	Mean	SD
Post-intervention	High ability	9	25.89	2.09
	Medium ability	17	22.00	1.84.
	Low ability	10	15.45	2.50
Pre-intervention	High ability	9	25.44	1.88
	Medium ability	17	18.78	3.70
	Low ability	10	12.40	1.90

N = frequency   *SD = standard deviation

To determine whether there is a statistically significant interaction between students' performance on the pre- and post-intervention tests regarding their ability levels, a multivariate analysis (two-way ANOVA) was conducted and the result shown in table 7. The results show that there is a significant difference among the 3 levels of student ability, since the F test statistic (98.03) in the ANOVA table is greater than the F critical value (6.35) in the F distribution table.

Table 7: Two-way ANOVA for Pre- and Post-intervention Test Scores Based on Student Ability Level

Source	Sum of Squares (SS)	df	Mean Squares (MS)	F Stat.	Partial Eta Squared (η^2)
Treatment	1358.66	2	679.33	98.03	.69
Error	602.91	33	6.93		
Total	1961.57	35			

df = degree of freedom   *F Stat. = F statistic

The fact that there is a significant difference among the ability groupings of students (F Stat, 98.03 > F Crit., 8.09) with a high effect size (partial η^2 = .69) in the pre- and post-intervention test scores requires a Tukey HSD post hoc test to identify which pairs of ability groups have the most significant difference. As shown in Table 8, the mean differences among all ability groups are significant. Particularly, the highest mean difference is observed between the high ability group and the low ability group (MD = 11.67), followed by the mean difference between the medium ability and the low ability groups (MD= 6.39), to conclude with the mean difference between the high ability and the medium ability groups (MD = 5.28). Hence, null hypothesis two stating that there is no statistically significant difference between the performance of different ability learners on assessment scores is rejected.

Table 8: Post Hoc Test for Students' Scores Based on Ability Levels

(A) Ability of students	(B) Ability of students	Mean difference (A-B)	Standard error	Significant or not
High ability	Medium ability	5.28	.72	Significant
	Low ability	11.67	.85	Significant
Medium ability	High ability	-5.28	.72	Significant
	Low ability	6.39	.68	Significant
Low ability	High ability	-11.67	.85	Significant
	Medium ability	-6.39	.68	Significant

4.2.3 Research question three

What is the impact of computer simulation instructional strategy on the attitude of students toward biology?

The computed descriptive statistics from Table 9 reveal that after the students were taught using the computer simulation instructional approach, they had a more positive attitude towards biology (Mean gain = 12.19) than when they were not exposed to the computer simulation instructional strategy.

Table 9: Descriptive Statistics for Students' Attitude toward Biology

Number of Students	Pre-Attitude		Post-Attitude		Mean Gain
	Mean	**SD**	**Mean**	**SD**	
36	75.36	8.20	87.55	7.10	12. 19

A paired t-test analysis on the data to determine whether the pre-attitude of students towards biology differ significantly from their post-attitude after computer simulation instructional strategy was used, as indicated in Table 10 below revealed that this mean difference was statistically significant ($P = .000 < .05$).

Table 10: Paired Sample t-Test on the Effect of CSIS on Students' Attitude toward Biology

Statistic	Pre-Intervention Attitude	Post-Intervention Attitude
Mean	75.36	87.55
Stnd. Deviation	8.20	7.10
Observations	36	36
Hypothesized Mean Difference	0	
df	35	
t Stat	9.579942704	
P-value	0.00	
t Critical	1.965942324	

Effect size

The Cohen's d procedure, d = $\frac{\bar{X}2-\bar{X}1}{s}$ was used to calculate the effect size of the difference in attitude of the students towards biology before and after computer simulation instructional strategies were used to teach biology. Therefore, $\bar{X}1$= 75.36, $\bar{X}2$ = 87.55, s = 8.20 (Table 10)

i.e., d = $\frac{87.55-75.36}{8.20}$

d = 1.4

An interpretation of the effect size is illustrated in Table 11. It shows various effect sizes along with suggested rise in attitude.

From Table 11, an effect size of 0.02 to 0.2 signifies a` 50% to 58% increase in attitude towards the subject; 0.5 effect size correspond to 69% increase in attitude whereas 0.8 to 1.4 effect size indicate 79% to 92% rise in attitude respectively.

Table 11: Cohen's Suggested Interpretation

Relative size	Effect size	% of Pre-attitude below Post-attitude
	0.02	50%
Small	0.2	58%
Medium	0.5	69%
Large	0.8	79%
	1.4	92%

An effect size of 1.4 implies that computer simulation instructional strategy has a large positive effect on the attitude of students towards the study of biology. Hence, it is inferred that computer simulation instructional strategy is an effective approach to teaching biology in order to increase students' attitude towards the subject.

4.2.4 Research question four

To what extent does the performance of male students on biology tasks differ from that of female students after using computer simulations to teach biology?

Table 12 shows the means between the male and the female after both the Pre- and Post-intervention tests. It also indicates standard deviation differences between the male and female students after both the Pre- and Post-intervention tests. In addition, the number of respondents in each case were 20 and 16 for the male and female students respectively. In Table 12, the male and female pre-test mean scores were 12.39 and 12.54 respectively while the standard deviations were 2.56 and 2.84 for males and females respectively. Again, in the post-test, the mean scores were 21.02

and 22.38 with standard deviations of 4.67 and 3.61 for males and females respectively.

Table 12: Mean and Standard Deviation Differences by Gender

Test type	Treatment	N	Mean	SD	SE
Pre-test	Male	20	12.39	2.56	.37
	Female	16	12.54	2.84	.36
Post-test	Male	20	21.02	4.67	.67
	Female	16	22.38	3.61	.45

N = frequency ****SD = standard deviation*** ****SE = standard error***

Test of hypothesis three

There is no statistically significant difference between the ach performance of male and female students on biology tasks after using computer simulations to teach biology.

To test research hypothesis three, the post-intervention test scores of the male and female students were subject to the t-test analysis. The results of the test are presented in Table 13. The mean difference between the performance of the male and female students on the post-intervention test is 1.36 in favour of the females. However, when the t-test was run, the p-value (.098) was found to be greater than the alpha value (0.05). This means that there is no sufficient evidence to say that the performance of the female students is significantly different from the performance of the male students on the post-intervention test. As such, the researcher failed to reject the null hypothesis three. It is inferred that the computer simulation instructional strategy can be used to enhance the performance of male and female students in biology equally.

Table 13: Independent Sample t-Test for Post-intervention Test by Gender

Statistic	Male	Female
Mean	21.02	22.38
Stnd. Deviation	4.67	3.61
Observations	20	16
Hypothesized Mean Difference	0	
df	34	
P-value	0.098	

4.3 Discussions

4.3.1 Performance of students in biology before and after the use of computer simulation instructional strategy to teach biology

The data presented in this chapter were based on the performance of students on a standardised performance test in biology [SATiB] administered twice, first as a pre-intervention test and then after the implementation of the intervention as a post-intervention test. Results from the pre-intervention test showed that there was low performance among the students (M = 12.58; SD = 2.98). This shows that prior to the intervention, the students had weak understanding of the tested content. Data related to the post-intervention test, which took place after implementation of the intervention showed that the students achieved a higher mean score (M = 23.32) on the post-intervention test than they did on the pre-intervention test. The mean difference between the performance of the students on the pre- and post-intervention tests was measured at 10.74. A t-test analysis of the data showed the mean difference to be statistically significant p-value (.00) < 0.05 (Table 3). It is depicted from these results that the intervention of computer simulation had a positive impact on students' performance in biology, specifically in the topic of “Cell Biology”. This positive impact may be due to the high interactivity of computer simulations. The interaction level of students with a computer simulation allows students to experience the content of biology rather than passively hear about it. As a result, the student is not limited to only observing and listening as is the case in most traditional classrooms, but he can expand his interaction with this technology to investigating different outcomes that result from different settings that he/she have control of. Consequently, the student would understand the biology concept or process presented in the simulation from different perspectives and different angles, resulting in a more profound and meaningful understanding of concepts and a higher mastery of processes. Based on the literature review, many studies (Podolefsky, Perkins & Adams 2010; Rieber, 2010; Salomon, & Perkins, 2016; Yeboah, 2010) reported similar impact for computer simulations on students’ learning of biology. In this study, the success of simulations in enhancing students’ learning was attributed to the “engaged exploration” offered by the simulation, as students were able to use the simulations to explore the topic of “Cell Division” in ways that were similar to how the real process happens. Another factor that contributed to the success of simulations in this study was the high level of interactivity with dynamic and immediate feedback to the students.

Also, Adams *et al*. (2008) reported positive impact of simulations that were used in their study to teach students about “Cells”. In this study, the authors related the positive impact of simulations to enabling students to see an animated motion of how materials are moved across the cell membrane by simple and facilitated diffusion. McKagan *et al*. (2008) have also reported positive impact of computer simulations on students’ learning of “Quantum Mechanics”. In their study, they conveyed that the impact was due to the high interactivity of the simulations, allowing students to adjust controls and observe animated response. This helped students establish cause- and-effect relationships, and construct understanding and intuition for abstract quantum phenomena. Another factor that made simulations effective in this study was their capability to quickly perform complex calculations. This feature relieved students from spending time and effort on calculations, and let them focus more on understanding the concepts without digging into math.

4.3.2 The effect of computer simulation instructional strategy on the performance of different ability level learners taught biology using computer simulations

When students' scores on the pre-intervention test were compared among their different ability levels, a two-way analysis of variance showed that there are significant differences among all ability levels (F Stat, 98.03 > F Crit., 8.09). More specifically, a post- hoc test showed that the highest significance is observed between the high and low ability groups (mean difference = 11.67), followed by the one between the medium and the low ability groups (mean difference = 6.39) and then by the one between the high and the medium ability groups (mean difference = 5.28). These results can be considered as normal, because high ability students are expected to perform at a higher level than their peers of the medium and low abilities. However, the results also show that the difference in the performance of the high ability learners on the pre- and post-intervention tests is very minimal (mean difference = 0.45) compared to the difference in performance on the pre- and post-intervention test by the low ability learners (mean difference = 3.05) and the medium ability learners (mean difference = 3.22). This shows that perhaps, computer simulations had a greater impact on low ability and medium ability learners than on the high ability learner. As such, it is inferred that computer simulation instructional strategy can be used to enhance the performance of low ability and medium ability learners in biology. The fact that high ability students did not have a significant gain from simulations may be explained by the capability of those students to build their knowledge and understanding by either using videos and animations, or by using simulations as assistive technology. This type of students has intrinsic motivation to learn, and high cognitive abilities that allow them to relate to any kind of technology, and use it to develop their knowledge. On the other hand, medium and low ability students may have profited more from simulations because they were engaged by the high interactivity of simulations, which offered them a technological platform where they had full control of the outcomes, and where they had the freedom to learn at their own pace by repeating the simulations as much as they wanted and receiving immediate feedback to build their knowledge. The results presented in this study regarding the impact of simulations on students of different abilities were similar to other studies reported in the literature. Yildiz and Atkins (2016) found that the same simulation could have different impact on students of different genders and prior performance levels. In their study, medium ability students showed great improvement upon using simulations when learning about "Photosynthesis". Yildiz and Atkins explained these results by claiming that these students took advantage of the possibility to repeat the same experiment many times to build confidence in their understanding. However, in the same study, high achieving students showed fewer promising results after using the same simulations. This was attributed to the fact that the lack of challenge in using computer simulations might have caused boredom and loss of concentration for these students. However, Chang, Chen, Lin and Sung (2008) conducted a study that presented outcomes that are different from those presented in the present study. Their study focused on the impact of learning support on simulation-based learning in three learning models: experiment prompting, a hypothesis menu, and step guidance. Also, the study took into consideration the different levels of abstract reasoning of students. Results showed that students with higher abstract reasoning level benefited from the simulations more than their peers of lower abstract reasoning level.

4.3.3 The impact of computer simulation instructional strategy on the attitude of students toward biology

The result of the study shows that the computer simulation instructional strategy significantly improves the attitude of students towards biology ($P = .00 < .05$). This compares favourably with the findings of Choi and Gennaro (2017) who opined that live simulation improves the attitude of students towards science and science learning. Additionally, a large effect size ($d = 1.4$) implies that computer simulation instructional strategy has a large positive effect on the attitude of students towards the study of biology. Hence computer simulation instructional strategy proves to be an effective instrument for bolstering the attitude of students towards biology. Students developed positive attitude towards biology because computer simulation instructional strategy provide a drive for students to be actively involved in their own learning. It creates a feeling of enjoyment and interest among students which in turn bolster their performance in a particular subject.

4.3.4 Differential effect of computer simulations on performance by gender

When the pre-test and post-test scores were analysed based on the gender of the student, the results showed that there was no statistically significant difference in the mean scores of male and female students ($p = 0.098 > 0.05$). Even though not statistically significant, the results revealed that the female students performed slightly better on both tests than their male counterparts. The performance scores of girls and boys may be attributed to the changing socio-cultural environment which has widened the scope for equal educational opportunities. Education systems have made significant strides towards closing the gender gap in educational attainment in recent decades (Khoo & Koh, 2018). It is thus inferred that computer simulations can be used to enhance the performance of both male and female students equally in biology. These findings are supported by many other studies which revealed no statistically significant mean difference between boys and girls with respect to performance and attitude toward biology (Kent & McNergney, 2019).

The overall results of the study indicated that the use of computer simulations in teaching improved students' performance in and attitude to biology at senior high school level with higher performance gains by both male and female students. The results of the study are consistent with the literature.

CHAPTER FIVE

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

5.0 Overview

This chapter covers the summary of the study, conclusions and recommendations arrived at, as well as suggestions for further studies. The purpose of this study was to investigate the effect of computer simulation instructional strategy on SHS students' performance in biology. The researcher aimed to determine if there were any differences between the learning outcomes of the students before and after computer simulation instructional strategy was used. Furthermore, the study sought to find out whether computer simulation instructional strategy have any differential effect on the performance of male and female students who were taught biology. The summary of key findings, recommendations and suggestions for further study are presented next.

5.1 Summary of Findings

This study investigated the effect of computer simulation instructional strategy on SHS students' performance in biology. The study's participants included thirty-six (36) SHS students. Standardised achievement test in biology [SATiB] was the main instrument used to collect data to answer the four research questions posed. Given below is a summary of the findings according to research questions.

5.1.1 Performance of students in biology before and after the use of computer simulation instructional strategy to teach biology

The performances of the students on the post-intervention test which was conducted after computer simulation was used to teach biology was shown to be significantly better than their performance on the pre-intervention test; signifying that SHS students exposed to the computer simulation instructional strategy performed significantly better in biology. This indicates that the use of computer simulations appears to have a positive influence on students' understanding of the concept of cell biology.

5.1.2 The effect of computer simulation instructional strategy on the performance of different ability level learners taught biology using computer simulations

The study showed that students of high ability scored nearly the same in the pre- and post-intervention test, while students of medium and low abilities scored significantly higher on the post-intervention test than the pre-intervention test; showing that computer simulations impacted medium and low ability students more than high ability students. These findings were discussed in the context of previous research findings such as those reported by Podolefsky, Perkins and Adams (2010), Adams, Reid, LeMaster, McKagan, Perkins, Dubson, and Wieman (2008), McKagan, Perkins, Dubson, Malley, Reid, LeMaster, and Wieman (2008), Adegoke & Chukwunenye (2013).

5.1.3 The impact of computer simulation instructional strategy on the attitude of students toward biology

Computer simulation instructional strategy proves to be an effective instrument for bolstering the attitude of students towards biology. The large effect size recorded from the findings implies that students developed a positive attitude towards biology perhaps because computer simulation instructional strategy provide a drive for students to be actively involved in their own learning. It creates a feeling of enjoyment and interest among students which in turn bolster their attitude to the subject.

5.1.4. Differential effect of computer simulations on performance by gender

Gender proved indifferent in the acquisition of biological concepts in cell biology when computer simulations were used. Female students performed marginally better than male students, although the t test showed insignificant difference in the mean scores of male and female students. This suggests that the use of computer simulation instructional strategy to teach biology equally favoured both male and female students.

5. 2 Conclusions

The following conclusions were drawn on the basis of the statistical analysis and the findings of the study. The results of the study imply that students exposed to the teaching and learning of cell biology through the use of computer simulations performed significantly better on post-intervention test than on pre-intervention test. On the basis of performance on pre- and post-intervention tests by ability levels, computer simulations proved to benefit low and medium ability learners more than high ability learners. Concerning the effect of computer simulation instructional strategy on the attitude of students towards biology, the study reported that computer simulations have a large positive impact on the attitude of students towards biology. Finally, considering performance on pre- and post-intervention tests by gender, the study concluded that the use of computer simulations in teaching and learning of concepts in biology such as cell biology equally favoured both male and female students.

5.3 Recommendations

Based on the major findings of this study, the following recommendations are offered.

- Science teachers at Kent International School should expose students to computer simulation instructional strategy (multimedia instructional strategies) so as to promote effective and active learning and learning by experience among students.
- Teacher education programmes in Ghana should develop courses, or training sessions, that show teachers how to design a computer simulation by themselves; teachers should be taught to design and implement computer simulations in their classes based on the topic they are supposed to teach and based on the level of students that are expected to use the simulation.
- The Ghana Education Service [GES] should make available ICT equipment that can facilitate the implementation of CSIS in biology classrooms.

5.4 Suggestion for Further Research

The results gathered from this study showed a positive relationship between CSIS and students' performance in and attitude to biology. Further research should be conducted to investigate the use of CSIS by science teachers and the factors militating against its use in science classrooms.

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